GEOMORPHOLOGY OF MARGUERITE BAY, PALMER PENINSULA, ANTARCTICA

Compiled by

RONNE ANTARCTIC RESEARCH EXPEDITION

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Prepared by

Robert L. Nichols

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FOREWORD

Submitted herewith is a report entitled "Geomorphology of Marguerite Bay, Palmer Peninsula, Antarctica." The report was compiled by Professor Robert L. Nichols of Tufts College in his capacity as geologist with the Ronne Antarctic Research Expedition. This report is the twelfth in a series containing scientific information gathered by the expedition which was sponsored by the Geophysics Branch of the Office of Naval Research.

GORDON G. LILL
Head, Geophysics Branch
Office of Naval Research

PREFACE

Technical Report number 12 is one in a series completed by members of the Ronne Antarctic Research Expedition 1946-48. This report was prepared by Dr. Robert L. Nichols, geologist, who was in charge of the geological investigations for the expedition.

In this report the geomorphology of the Marguerite Bay, Palmer Peninsula Area of Antarctic, is presented. Sledging from the expedition's wintering base on Stonington Island, Dr. Nichols and his assistant, Robert H. T. Dodson, spent 150 days out of 470 in the field gathering data and geological specimens. This is an excellent record considering the working conditions which are prevalent in the Antarctic.

The expedition was supported by the Office of Naval Research, among others, under Contract N6onr-280. This report was sponsored by the Office of Naval Research under separate Contract Nonr-979(00) with Tufts College, Medford, Mass., where Dr. Nichols is engaged as a professor of geology

The geological program of the expedition would not have been possible without the assistance and cooperation of the Office of Naval Research. I am also indebted to the expedition's aviation-group for the constant support they gave the geological party in the field.

FINN RONNE, CDR. USNR
Expedition Leader

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INTRODUCTION

During the period from March 1947 to March 1948 the writer, while a member of the Ronne Antarctic Research Expedition, made geologic studies in Marguerite Bay, Palmer Peninsula, Antarctica (Fig. 1). Approximately 54 9-hour days were spent in geologic study at the following widely-scattered localities: Alexander I Island, Mushroom Island, Terra Firma Islands, Cape Berteaux, Windy Valley, Black Thumb Mountain, Red Rock Ridge, islands between Red Rock Ridge and Black Thumb Mountain, Neny Fjord, Neny Island, Stonington Island, Roman Four Promontory, islands approximately 10 miles southwest of Adelaide Island, and islands approximately 50 miles west of Stonington Island (Fig. 2)

To accomplish this, the writer was on the trail for approximately 150 days and was a member of the expedition for about 470 days. The ratio of full days spent on geologic study to the total time spent on the trail was, therefore, approximately 1:3, and the ratio of days spent on geologic study to the total time spent on the expedition was about 1:9. These are good ratios for Antarctic field work. They are due primarily to the excellent support given to the geologic program by Commander Finn Ronne, to able field assistants, and to a good bit of luck with meteorological conditions, sledging surfaces, and sea ice permanence.

Participation on the expedition was made possible by a generous grant from the Geological Society of America and by a leave of absence from Tufts College. The writer would like to record deep appreciation to Dr. Henry A. Aldrich, Secretary of the Geological Society of America, who was responsible for this grant and to Dr. Leonard Carmichael, President of Tufts College, who was responsible for the leave of absence.

Warm-hearted thanks to Mr. Robert H. T. Dodson must be made. He was the writer's sole companion on a 90-day sledge trip, one of his companions on a 30-day sledge trip, and he worked with him on many local outcrops. He was a stimulating and pleasant field assistant and a resourceful and hardworking trail man. His interest in the geologic problems and the efforts which he made to help solve them will always be remembered.

Special mention should also be made of Mr. William R. Latady who spent many days with the writer on the trail and who, as an expert photographer, was of great help

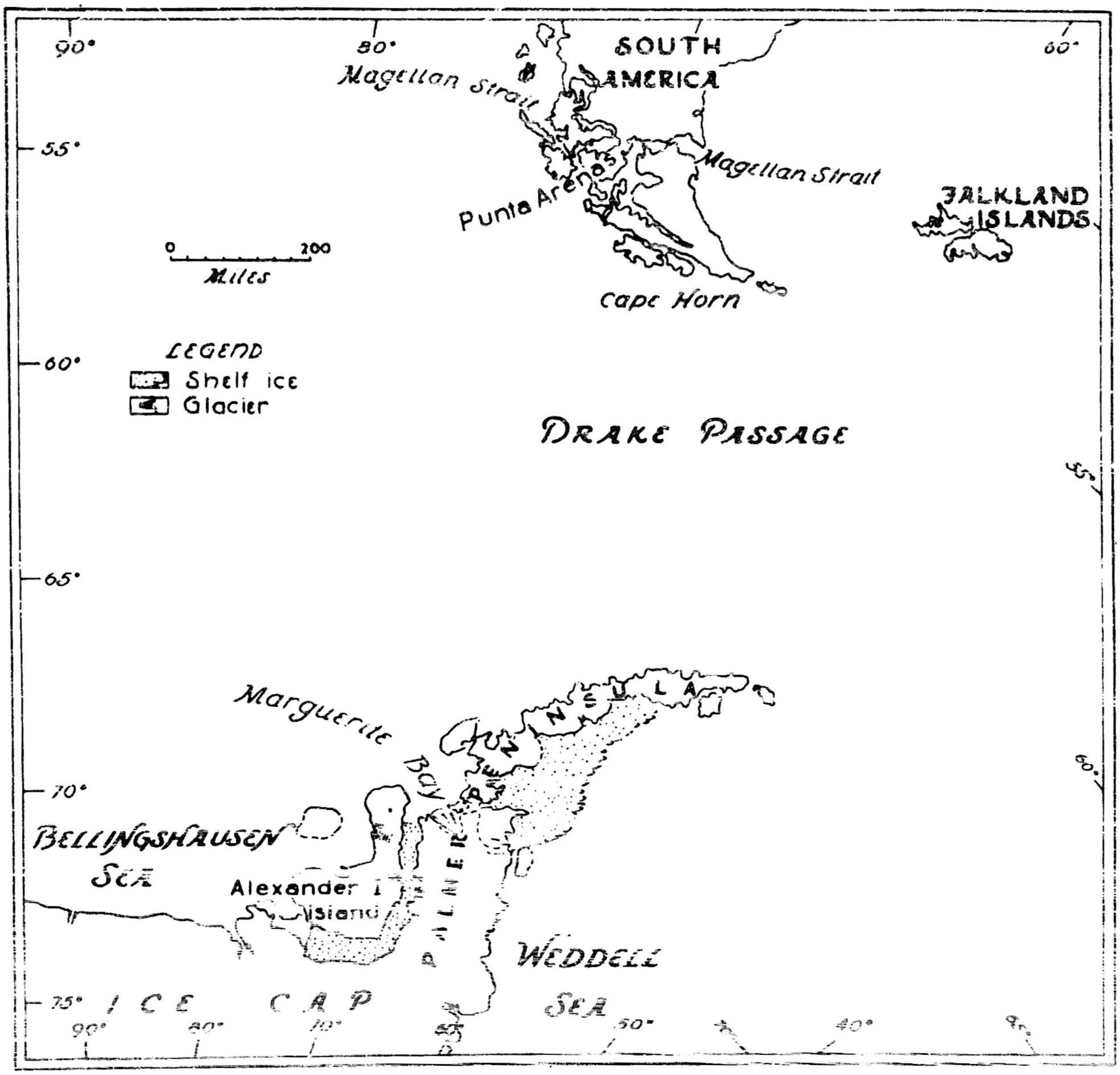

Figure 1 - Map Showing South America, Drake Passage, Palmer Peninsula, and Marguerite Bay

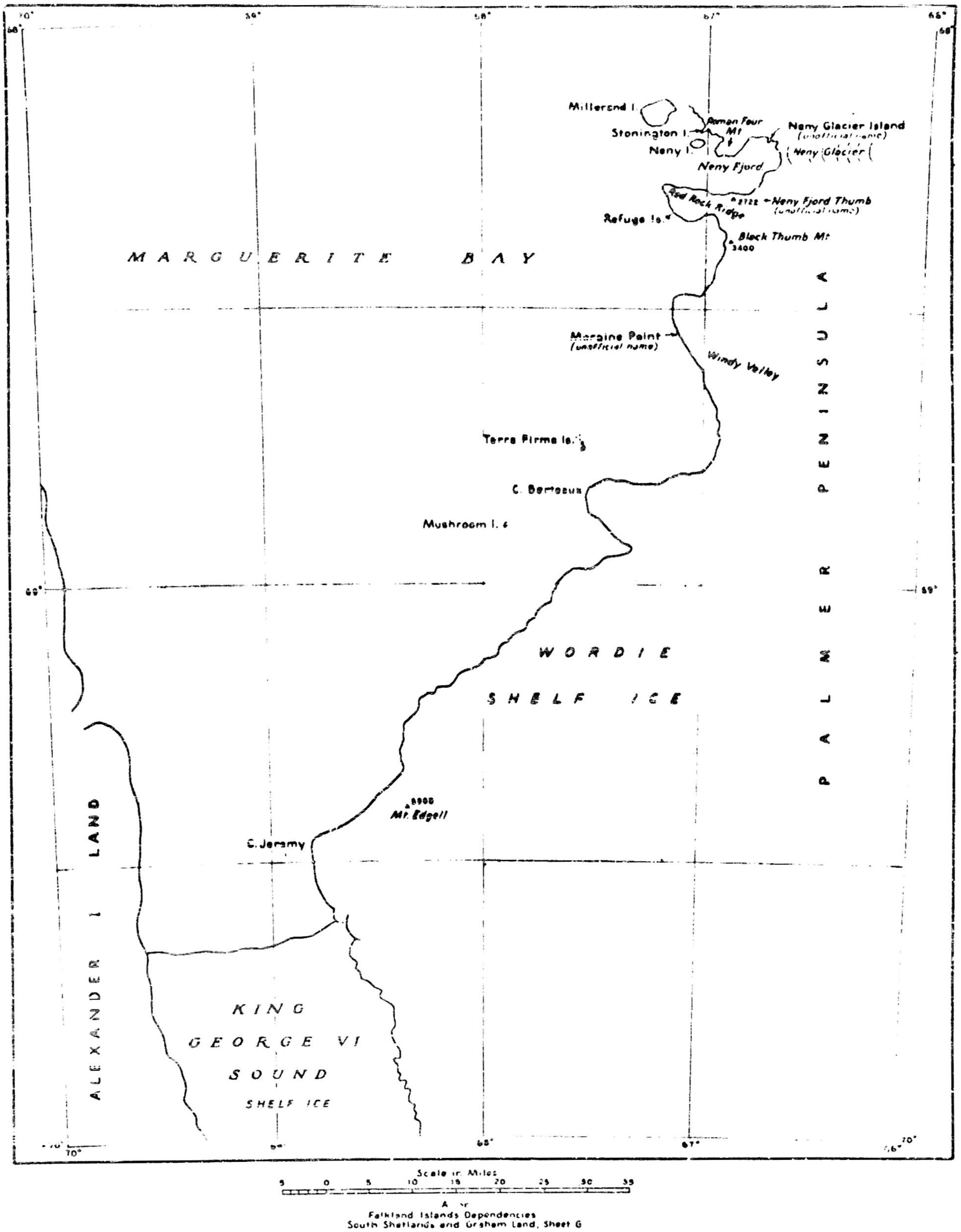

Figure 2 - Index Map Showing the Localities Studied in the Marguerite Bay Area

It is a pleasure to acknowledge the interest, cooperation, and help which I received from the other members of the expedition and from the members of the Falkland Islands Dependencies Survey

Prof. Marland P. Billings and Dr. Lawrence E. Nielsen have discussed several of the problems with the writer and have made valuable suggestions.

Prof. Charles E Stearns critically read the manuscript and made many pertinent suggestions

Lastly, I take great satisfaction in acknowledging Commander Finn Ronne's keen interest in the geologic program; his understanding of the importance of the work and the kinds of problems solved; the dogs, food, equipment, airplane support, and personnel which he made available for the geologic sledge trips, and his many personal kindnesses

DESCRIPTION OF AREA

The Palmer Peninsula (Graham Land) runs nearly north and south and is the northernmost part of the Antarctic Continent (Fig 3) It is separated from the southern tip of South America by the Drake Passage which is approximately 600 miles wide. The Palmer Peninsula extends from approximately 63°S on the north to 74°S on the south; and from about 57°W on the east to 69°W on the west. It joins Edith Ronne Land to the east and the Robert English Coast to the west, both of which are on the main part of the continent (U S Navy Dept., 1943, H O. no. 2562, Ronne, 1948, Figure 1). The coast on both sides of the peninsula is characterized by indentations, inlets, bays, and fjords; and by islands and bold headlands. The backbone of the Palmer Peninsula is a snow-covered plateau about 2000 feet high at the northern end which gradually increases in altitude to about 6000 feet at the southern end A large percentage of the peninsula is covered with highland ice and snowdrift ice slabs, with valley piedmont, tidewater, cliff, cirque, outlet, and fringing glaciers; and with extensive areas of shelf ice which are found on both the east and west coasts A good description and excellent photographs of the area are found in Sailing Directions for Antarctica (U S. Navy Dept , 1943, H.O no 138, pp 109-169).

Marguerite Bay is located along the southwestern part of the peninsula. It is bounded on the north by Adelaide Island, on the east by the Fallieres Coast, on the south by King George VI Sound, and on the southwest by Alexander I Island (Fig 1)

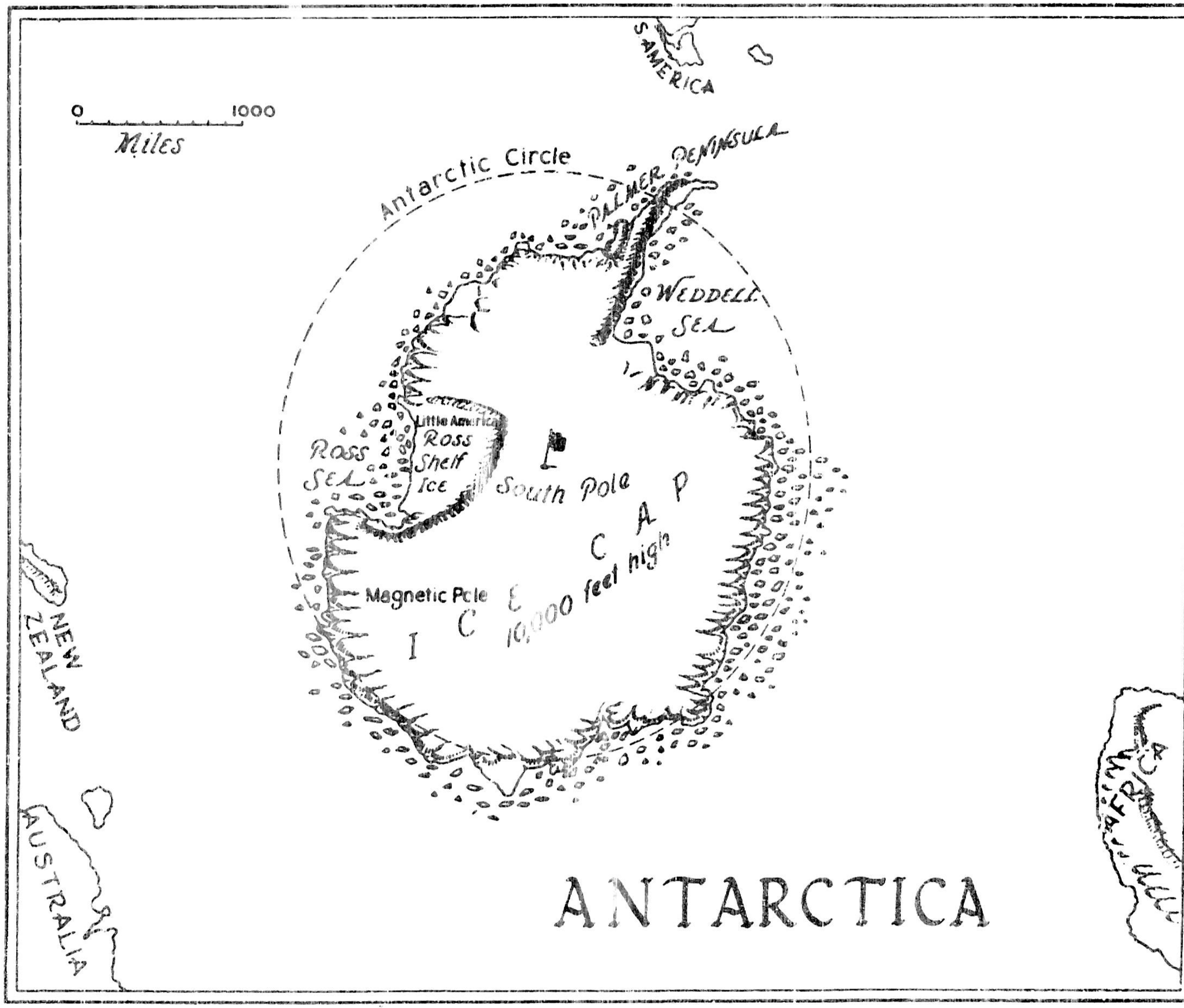

Figure 3 - Map of Antarctica Showing the Location of the Palmer Peninsula

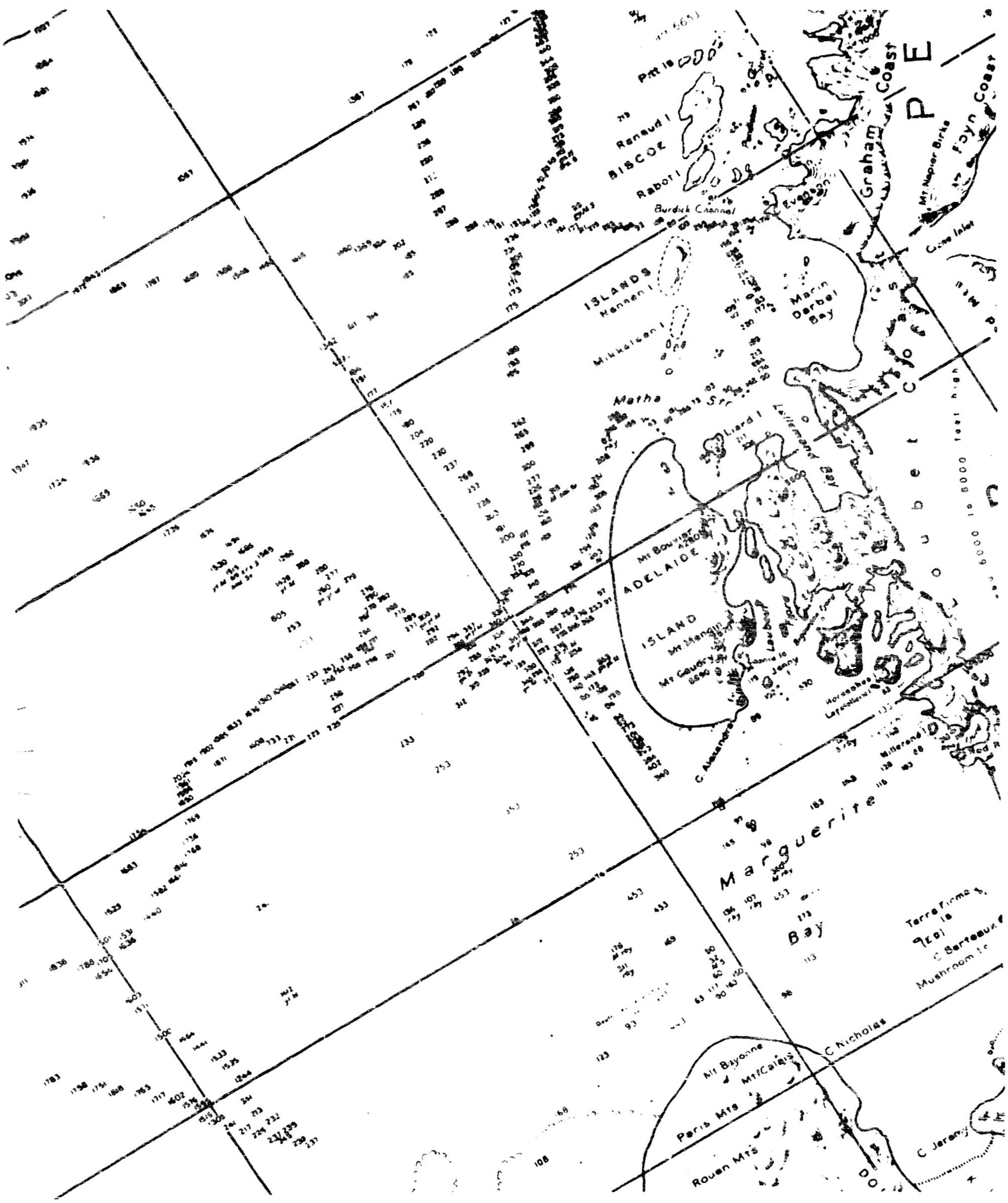

Figure 4 - A part of Chart No. 5411 Published in 1946 by the U.S. Navy Dept., Hydrographic Office (Soundings in Fathoms)

PENEPLAIN

The summit of the Palmer Peninsula is a snow-covered plateau. About 2000 ft high in the northern part of the peninsula, it gradually increases in altitude southward and in the southern part it reaches a height of 6000 or more feet (U.S. Navy Dept., 1943, H.O. no. 138, p 109). The U.S. Army Air Forces aeronautical charts Adelaide Island (1762) and South Shetland Islands (1737) show the plateau to be 6000-8000 ft high between 66°30′S and 68°00′S, approximately 6000 ft high between 65°30′S and 66°30′S, 4000-6000 ft high at 64°00′S, and 2000 ft high from 64°00′S northward. Bedrock crops out near the summit of the plateau around the top of Richthofen Valley which is between 65°30′S and 66°00′S, and there are three bedrock mountains which project above the plateau between 63°10′S and 63°30′S. The Falkland Islands Dependencies, South Shetlands, and Graham Land Chart (Sheet C) shows a very flat area at about 5000 ft between 67°30′S and 68°00′S and a plateau above 6000 ft between 66°00′S and 66°30′S. Bedrock is shown not far below the summit of the plat u in both of these areas.

The plateau is present east of Stonington Island (Nichols, 1947b; 1948a, pp 3-4) (Fig. 5) and is well developed immediately north and south of the terminus of Neny Glacier (Fig. 6) (Dorsey, 1945, Figs. 1,2). Its distribution in this area is shown on a map made from a survey by A. Stephenson (Rymill, 1938, p 432, see also p 400). Two remnants of the plateau are located between Cape Berteaux and Windy Valley (Fig. 7), another is found southwest of Black Thumb Mountain (Debenham, 1937, p 253), and an extensive flat remnant is found near Mount Edgell (Fig. 8). In the vicinity of Stonington Island there is an area of peaks, ridges, promontories, and valleys between the plateau and the coast, decreasing in altitude westward, which has probably resulted from the dissection and erosion of the plateau. The plateau is, therefore, hundreds of miles long, where badly dissected it is only a few miles wide, and in other places it is scores of miles wide.

The members of the Falkland Islands Dependencies Survey and the Ronne Antarctic Research Expedition who have sledged on the plateau east of Stonington Island have reported it to be very flat with an occasional domal mountain rising 300-400 ft above it.[1] This smoothness is due in part to the presence of the highland ice-cap which covers the plateau. Mount Edgell is a domal mountain which rises 1,800 feet above the plateau remnants which surround it, and to the south there are peaks which rise even higher above the plateau.

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[1]Personal communications from Mr. Arthur Owen, Ronne Antarctic Research Expedition, and Mr. Kevin Walton, Falkland Islands Dependencies Survey.

Figure 5 - The Uplifted Peneplain East of Stonington Island

Figure 6 - The Uplifted Peneplain Several Thousand Feet Above Sea Level Immediately South of Neny Glacier (Horn formed by dissection of peneplane, which is veneered by highland icecap)

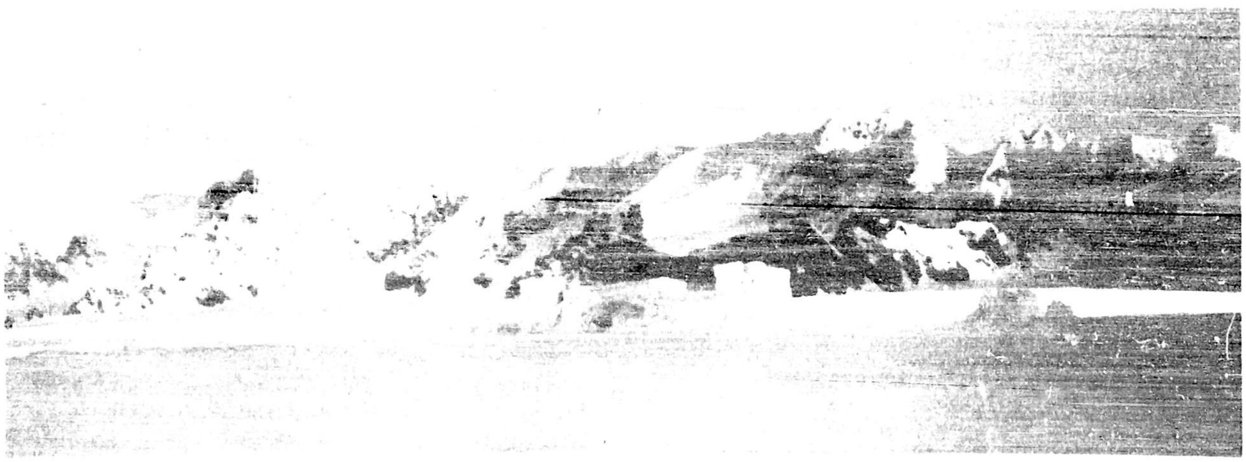

Figure 7 - The Uplifted Peneplain South of Stonington Island

Figure 8 - The Highland Icecap on the Uplifted Peneplain
Near Mt. Edgell

LCDR E. W. Bingham and Mr. A. W. Reece, both of the Falkland Islands Dependencies Survey, who have done considerable sledging on the plateau, told the writer that they never saw an outcrop on it (Fig. 9). This is also due to the highland icecap. In the northern part of the Palmer Peninsula from 63°00'S to 66°00'S the plateau according to Andersson (1906, pp 25-31, pl 5) cuts folded Jurassic greywacke, slate, and volcanic tuff and also granite, quartz-diorite, and gabbro. Immediately north of the terminus of Neny Glacier the plateau cuts pink granite and gabbro, and east of Stonington Island Knowles (1945b, map 1) found plutonic igneous rocks on the plateau. It seems likely that elsewhere in the Marguerite Bay area the plateau may also cut schist, gneiss, and argillite; a younger group of related intrusives including pyrobolite, gabbro, diorite, and granite; and a still younger series of volcanic tuffs, breccias, and agglomerates together with a red, vuggy granite which intrudes them, as all of these are cut by surfaces younger than the plateau in the coastal area west of the plateau (Nichols, 1948a, pp 1-3). Where it has been studied, and probably everywhere else, the plateau is therefore an erosion surface (Howard, 1950, pp 1472-1473). Nothing is known of the mantle rock deposits on it.

The group of related intrusives which includes pyrobolite, gabbro, diorite, granite, and other rock types is probably post-Jura-Cretaceous, as the granite cuts argillites which are probably of this age (Nichols, 1948a, p 3). Correlation with similar rock types in South America indicates that they are probably Cretaceous (Stose, 1950, Geol. Map S.A.). Neither the volcanic series nor the younger granite can be precisely dated. The younger granite is cut by trap dikes which may correlate with the Miocene basaltic volcanics in the northern part of the Palmer Peninsula (Andersson, 1906, pp 45-50, 70) and with the Miocene basalts of Patagonia. Correlation with similar rock types in South America suggests that they may be early and middle Tertiary (Stose, 1950, Geol. Map S.A.). It is not known whether the plateau cuts the trap dikes in the Marguerite Bay area or the Miocene basaltic volcanics in the northern part of the Peninsula. The above analysis indicates that the plateau surface is either middle or late Tertiary. Most of the high-level erosion surfaces in other parts of the world are also of this age (Ashley, 1931, p 537).

It is not known whether the plateau is: (1) An uplifted peneplain. (2) An uplifted plain of marine denudation. (3) A surface formed by cryoplanation (Peltier, 1950) at an elevation above that at which peneplains develop which was subsequently uplifted, depressed, or stable. (4) A surface formed by erosion down to tree line (Daly, 1905) at an elevation above that at which peneplains develop which was subsequently uplifted, depressed, or stable. Among the criteria which have been used by geomorphologists to differentiate and identify these surfaces are:

Figure 9 - Marginal Crevasses in the Highland Icecap on the Uplifted Peneplain East of Stonington Island

(1) The degree of topographic adjustment to structure (2) The presence or absence of residual soils, fluvial deposits, marine deposits, periglacial deposits, and other deposits and features characteristic of these surfaces. (3) The flatness of the surface (4) The distribution of terraces. (5) The presence or absence of drainage patterns. The writer never worked on the plateau, and even if he had it is most unlikely that he would have been able to demonstrate its origin conclusively, as its surface features are masked and bedrock is almost completely covered by a highland icecap hundreds of feet thick.

The Antarctic, of all the regions of the world, is, because of its high latitude, perhaps the most favored locality for the formation of a surface due to cryoplanation On the other hand, the climate of the world for much of geologic time has been such that the action of ice has not been an important geomorphic process Moreover, there is no good evidence that the climate was such that ice was geomorphologically active on the Palmer Peninsula in middle or late Tertiary time. It seems unlikely that tree line, which is sensitive to many climatologic elements, would remain fixed long enough for the formation of an extensive flat erosion surface worn down to it

Both cryoplanation and erosion down to tree line are processes which could produce initial high-level erosion surfaces The possibility of erosion below the cryoplanation and tree line erosion surfaces, without diastrophic movement, makes the formation of continuous extensive flat surfaces by these processes unlikely The plateau increases in altitude from north to south If the plateau was formed by either of these processes, and was not diastrophically tilted subsequent to formation, it would probably decrease in altitude from north to south Peneplains, uplifted peneplains, and buried peneplains are much more common in the literature and presumably in nature than their marine counterparts. This is probably due to the rapidity with which peneplains are formed in comparison to plains of marine denudation (Johnson, 1919, pp 250-253) and to the fact that during the Tertiary when the continents were in general considerably elevated, peneplains could be formed everywhere whereas plains of marine denudation could only be formed near the continental margins.

The writer, in the absence of definite proof, is assuming that the plateau is an uplifted peneplain, as this is the conventional explanation for this type of feature The uplift was differential as the surface in the southern part of the peninsula was uplifted several thousand feet, whereas in the northern part it was uplifted less than 2000 ft. Nothing is known of the mechanism of uplift nor of the relation of the axis of uplift to the crest of the plateau The Pecten-conglomerate of Pleistocene age on Cockburn Island which is now more than 500 ft above sea

level indicates that some of the uplift of the peneplain in the northern part of the Palmer Peninsula has taken place since the conglomerate was deposited (Andersson, 1906, pp 50-53; Hennig, 1911).

Holtedahl (1935, p 12) recognized the presence of a dissected plateau in the northern part of the Palmer Peninsula. He interpreted it to be an elevated erosion surface. With regard to it, he wrote, "The north-western, coastal areas of Graham Land are known to consist to a large extent of once deep-seated igneous rocks, intruded during a period of alpine orogeny. The time of folding and intrusion of the Antarct-Andes according to Nordenskjöld is Upper Cretaceous or Older Tertiary. The plateau surface must consequently have been cut in a more recent time and finally, still later, probably because of an important uplift of the land, the intense dissection of the plateau started." Elsewhere he wrote (Holtedahl, 1935, pp 27-28), "After the time of mountain folding and intrusion (in younger Cretaceous or older Tertiary time) a pene-planation seems to have taken place in the Graham Land area during which time denudation worked down to once deep-seated rocks. In this eastern district much of the old, fairly even surface has survived until the present day, incisions, caused by a (relative) uplift of the area, being made chiefly on the flanks."

There is a suggestion of a summit peneplain on Alexander I Island when the island is viewed from the east. The existence of accordant summits on Alexander I Island is recorded by Joerg (1937, map B), the presence of a flat surface on top of Alexander I Island was noted by Ronne[1], who flew over and along the island several times, and photo-graphs taken by the Ronne Antarctic Expedition show this surface.

King George VI Sound has been assumed to be a tectonic valley (Joerg, 1937, pp 440-443; Fleming, Stephenson, Roberts, and Bertram, 1938, p 531; Stephenson, 1940, p 175; Fuchs, 1951, p 406) because of its straightness, length, width, and depth, and because of the difference in rock types and mountain ranges on opposite sides of the sound. On a basis of the data published about it, it could just as well be a structurally controlled erosional valley formed by stream and/or glacial erosion. If the peneplain has been formed and uplifted on Alexander I Island, it would seem as if King George VI Sound was formed after the peneplain was uplifted and probably in late Tertiary time. The submarine profiles which have been made of the continental shelf in Marguerite Bay give no indi-cation of either a down-faulting of the Sound or an up-faulting of Alex-ander I Island (U.S. Navy Dept., 1939, H.O. no. 5411). This may be due to the presence of cross faults running east and west, to considerable

[1] Personal communication from CDR Finn Ronne.

marine sedimentation since faulting, or to some other origin for the Sound.

SHORELINE OF SUBMERGENCE

The Palmer Peninsula is an excellent example of a shoreline of submergence and of a fjord coast. High bedrock islands, imposing promontories, irregular off-shore profiles, and high-walled fjords are common. They indicate that a mountainous area was submerged. The submergence must be due in part, at least, to the weight of the ice and to the glacial erosion which took place below sea level. It is not known whether it is also due to a depression of this part of the continent unrelated to glaciation. The continental shelf around the Antarctic is the deepest in the world (Shepard, 1948, p 141). Along the west coast of the Palmer Peninsula between 65°00'S and 68°00'S the break in slope appears to be between 1400 and 1600 ft (U.S. Navy Dept , 1939, H.O. no. 5411) (Fig. 4). According to Shepard (1948, p 143) the average depth for the break in slope, based on a study of the continental shelves of the world, is 432 ft. A rough measure of the submergence of the Palmer Peninsula is, therefore, 1000 ft.

Cliffs thousands of feet high are common along the fjords and on the promontories. They could have been formed by marine erosion, glacial erosion, or faulting. No evidence of large-scale faulting was observed during the reconnaissance field work. Wave-cut platforms associated with the cliffs and related to the present or earlier positions of sea level were not seen, although no submarine profiles or careful studies were made. The severity of the glaciation and the absence of faulting and wave-cut platforms indicate that the cliffs were formed, therefore, mainly by glacial erosion. The presence of the islands, promontories, and drowned valleys, and the apparent absence of wave-cut platforms suggest that the area is in the initial or youthful stage of the marine cycle.

Following the uplift, the peneplain was considerably eroded and dissected. The depression of the area took place in the Pleistocene after the uplift and dissection of the peneplain and after the elevation of the Pecten-conglomerate (Hennig, 1911). The submergence of the coast took place after the depression and glacial erosion and following deglaciation. The mountains of the Palmer Peninsula are, therefore, erosional and have resulted from the uplift and dissection of an erosion surface.

PRE-PLEISTOCENE ANTARCTIC GLACIATION

Because the Antarctic Ice-Cap has persisted long after the continental icecaps which covered North America, Europe, and elsewhere have disappeared, it might seem logical to assume that glaciation was initiated in the Antarctic before it started elsewhere. If the conditions which brought on glaciation appeared suddenly, however, the beginnings of glaciation may have been nearly synchronous on all the continents.

Wright and Priestley (1922, pp 183, 431-435), Priestley (1923, pp 10-11), and Gould (1939, p 739; 1940, pp 868-869) believe that glaciation started in the Antarctic in the Tertiary. Thus Wright and Priestley (1922, p 183) write, "The Antarctic Ice-Age must have commenced very soon after the volcanoes (of the Middle Tertiary) raised their heads above sea level," and Gould (1939, p 739) says, "The effective glacial erosion of Antarctica must have preceded the rest of the world . . . by a very great period of time. That it began in the Middle Tertiary, at least, and that the major erosional effects were produced in Late Tertiary rather than Pleistocene time, seems reasonable."

These geologists base the above statements on data which they believe prove the reality of Tertiary Antarctic glaciation. It is the opinion of the present writer that this thesis is not proved.

Gould (1940, p 869) writes, "According to Wright and Priestley (1922, p 183) the intercalated layers of ice and volcanic debris on the slopes of Mount Erebus on Ross Island at the northwest apex of the Ross Shelf Ice indicate that glaciation must have begun there in early Tertiary," and elsewhere he writes (1939, p 739), "The relationship of volcanic debris to intercalated layers of ice about Mount Erebus indicates that glaciation must have begun there in the Middle Tertiary (Wright and Priestley, 1922, p 183)." A reading of Wright and Priestley shows that Gould has misquoted them and that they do not believe in Tertiary Antarctic glaciation because of the presence of ice interbedded in volcanic material on the slopes of Mount Erebus.

If volcanic material is interbedded with ice on Mount Erebus, and Prof. David (1909, pp 185, 194-195) who made the observations was not sure that this was the case, it still does not indicate a Tertiary age for the ice, as the volcanic material was seen on the walls of the active crater of Erebus. The active crater is undoubtedly post-Wisconsin, probably historic, and perhaps only a few hundred years old. The active crater is higher than 12,000 feet above sea level and Debenham (1923, p 37) feels it is quite possible that that part of the volcano above 11,000 ft has changed greatly since Ross first viewed it in 1841.

Wright and Priestley base their belief in Tertiary Antarctic glaciation mainly on the occurrence of moraine-like deposits which have been found in both East and West Antarctica.

Andersson (1906, p 42) has described a deposit at Cape Hamilton, James Ross Island, Palmer Peninsula as follows, "Next above the Cretaceous beds follows a moraine-like mass, some meters in thickness: in a clayey matrix lie numerous angular fragments of crystalline rocks foreign to the locality (granite etc.; no volcanic rocks or porphyries were noticed amongst these fragments of plutonic eruptives and crystalline schists). Also pieces of claystone were noticed. The largest of these lumps of foreign rocks did not exceed half a meter in diameter; most of them were much smaller." Nordenskjöld (1911, pp 107-108) in describing and interpreting the same deposit writes, "Unmittelbar unter dem normalen Tuff liegt ein 2 m mächtiger harter, feinkörniger Tonsandstein mit zahlreichen vulkanischen Fragmenten und schöner Kreuzschichtung. Es scheint ein im Wasser abgesetzter tuffogener Sandstein zu sein. Unter ihm folgt eine noch mehr abweichende Bildung, ungeschichtet, viel weniger hart als die vorige und sehr zahlreiche, kantige Fragmente verschiedener Grösse, bis zu 0,4 - 0,5 m, von fremdem Gestein teils von einem Tonstein teils besonders von kristallinischen Gesteinen, hauptsächlich gneisartigen Schiefern, enthaltend. Grössere Basaltblöcke sah ich nicht, . . . Die Mächtigkeit war jedoch nicht gross, sie betrug nur einige wenige Meter. Sicher ist, dass der Eindruck ein auffallend moränenartiger war, und selbst wenn, was wahrscheinlich ist, eine Wasserablagerung vorliegt, so kann man sich schwer vorstellen, wie diese Masse von oft ziemlich grossen, kantigen Blöcken von Gesteinen, die nirgends in grösserer Nähe als 50-60 km anstehen, sich hier ohne Mitwirkung von Eis in irgend einer Form hat ansammeln können." In discussing this deposit Wright and Priestley (1922, pp 431-432) write, "It appears probable . . . that in this moraine-like bed above the Cretaceous . . . we have visible evidence of one swing of the climatic pendulum as the Tertiary refrigeration set in. Angular rock fragments in a clayey matrix are strongly suggestive of glacial action on a comparatively large scale."

In a description of bedrock found between Cape Karl Andreas and Cape Gunnar, Palmer Peninsula, Andersson wrote (1906, p 29), "Here a shore-nunatak exhibits a coarse conglomerate with boulders of up to 2 meters in diameter. In general the mass is quite unstratified and really much like a bottom-moraine, though the rock is evidently old and seems to have taken part in the mountain-folding. Only in one spot, where the conglomerate is less coarse, does it show slight indications of bedding. The material of the pebbles is very varied, beautiful porphyries being very common amongst many other kinds of rock."

In evaluating these two localities, described by Andersson, Wright and Priestley (1922, p 432) write, ". . it is therefore quite likely that the two deposits may have been more or less contemporaneous. If this is so, it should be noted that these form the first definite evidences of glacial conditions, on anything like a large scale, in the geological history of the Antarctic, . . ."

Cape Adare is composed of slightly dipping basaltic lava flows and intercalated beds of tuff and agglomerate, all of which are cut by numerous dikes (Priestley, 1923, p 8). Interbedded in this series, Priestley (1923, p 11) found what he thought were glacial boulders. His description of this material is as follows: "a coarse agglomerate containing numerous foreign boulders — granites, schists, trachytes, porphyries, etc. — which both from their heterogeneity and the shape of individual boulders are undoubtedly glacier borne erratics (Plate 11). . . . The erratics were not in one place but were scattered evenly through the rock. . . The largest blocks I saw were a block of quartzite (greywacke) whose exposed face was practically 12 inches by 14 inches, and a block of dolerite or norite which was well-rounded and of the typical triangular shape assumed by so many erratics. . . . We secured several specimens of fair size, including some granite boulders, with a good deal of tuff matrix adhering to them. Here we have undoubted evidence of the extension of the Ice Age back into the past, so far that glacial action, probably on a scale greater than that at the present day, was contemporaneous with some of the earlier of the Cape Adare lavas. Taken in conjunction with the evidence from West Antarctica . . . it is strong presumptive evidence of the existence of an advanced stage of a Glacial Cycle in Antarctica in mid-Tertiary times."

The various kinds of criteria useful in the indentification of tillite can be conveniently placed in the following three major categories: (1) Those connected with the kind of basement on which tillites sometimes rest. The polished, striated, and grooved surfaces, the roches moutonnées, and the other buried bedrock features belong here. (2) The presence of marine tillites, varved lacustrine deposits, glacio-fluvial beds, and the other deposits with which tillites are commonly associated. (3) The lack of sorting and stratification, the presence of angular, subangular, striated, and soled fragments, the variations in thickness, and the many other characteristics of tillite are found here. When a breccia has many criteria in all three categories, the stratigrapher usually has considerable confidence that the breccia is ice-laid. Criteria in all three categories are found in the case of the Dwyke Conglomerate of Africa and its glacial origin is universally accepted (Coleman, 1926, pp 116-128).

The Antarctic breccias described above, which prove Tertiary Antarctic glaciation according to Wright and Priestley, are not, as far as is

known, resting on glaciated basements, nor are they found with the deposits with which tillites are commonly associated. The only criteria presented which suggest a glacial origin for these breccias are (1) clayey matrix, (2) angular and triangular shaped fragments, (3) lack of stratification and sorting, (4) fragments composed of a variety of lithologic types (Sayles, 1914, pp 144-145; Wentworth, 1936, pp 91-92). These features, however, are characteristic not only of ice-laid deposits but also of mudflows, volcanic breccias, and fanglomerates.

Nordenskjöld (1911, pp 107-108), in his discussion of the moraine-like deposit at Cape Hamilton, pointed out that some of the fragments came from distances as great as 50-60 kilometers and were therefore probably ice-laid. The deposit is associated with volcanic breccias and the various lithologic types foreign to the area might just as well have come from depth.

In the opinion of the writer there is no good evidence for Tertiary Antarctic glaciation.

GLACIAL FEATURES

Smooth, rounded surfaces resulting from glaciation were found at Roman Four Mountain, Refuge Island, Moraine Point (unofficial name), Neny Glacier Island (unofficial name), and at other places. Bedrock basins resulting from glacial plucking were found on Stonington Island, on the islands approximately 50 miles west of Stonington Island, and elsewhere.

Glacial striations are very rare. They were not found on the mainland. However, the coarse-grained igneous rocks on two of the islands approximately 50 miles west of Stonington Island are striated and at one place glacial grooves and trenches are found on them. The argillites on the two islands which are 10-15 miles from Adelaide Island are in places excellently striated. Glacial striations are scarce on the mainland because of: (1) Destruction by wave action of those below the marine limit. (2) Destruction by frost weathering and other processes. (3) Coarse-grained igneous rocks which are the most common rocks on the mainland are not the easiest to striate nor are striations preserved on them as long as on some other rock types. (4) The basal load moved by the glaciers was not great.

U-valleys, cirques, horns, and aretes are common (Figs. 6, 10). A well-formed cirque now occupied by a glacier is located on the south side of Neny Fjord near the terminus of Neny Glacier (Fig. 11). The headwall is approximately 2000 ft high and the plateau veneered with

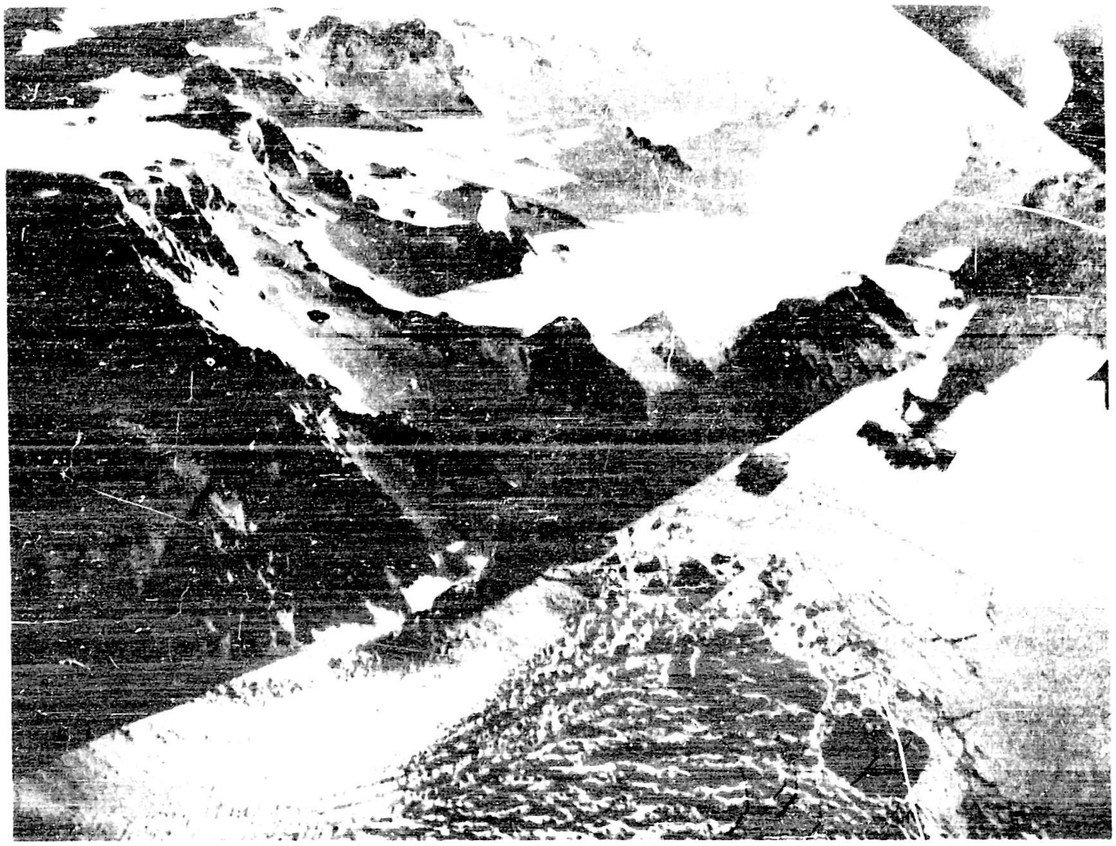

Figure 10 - The South Side of Terminus of Neny Glacier in 1948. Crevasses and formation of icebergs. Bay ice folded and cracked by thrust of glacier. Cirques, horns, aretes, and the highland ice flowing off the plateau in an outlet glacier.

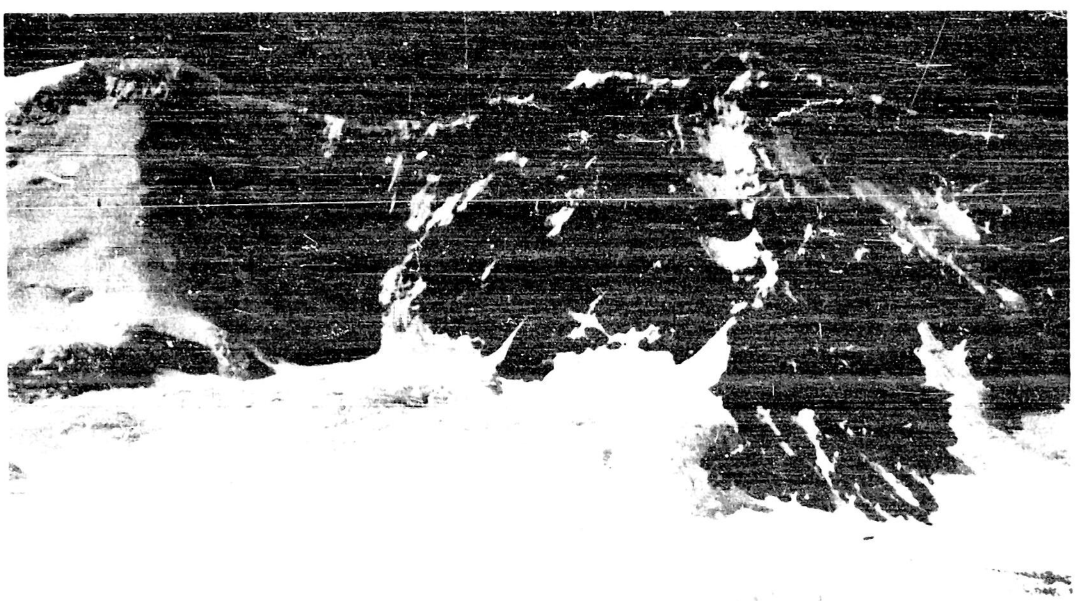

Figure 11 - Cirque, Cirque Glacier, Barrier, Bay Ice, and the Highland Icecap Near the Terminus of Neny Glacier

highland ice is found immediately above it. It was largely, if not completely buried during the Red Rock Ridge glacial stage. It is not known exactly how much of the cirque was formed in pre-Red Rock Ridge glacial time, how much in post-Red Rock Ridge time, nor how much modification occurred when it was overrun by the Neny Glacier during the Red Rock Ridge glacial stage. The absence of a prominent end moraine built up above sea level does not mean that the cirque was not enlarged in post-Red Rock Ridge time as the fjord may be deep and some of the material taken from the cirque by the local glacier could have been removed by Neny Glacier when it was larger. The slight asymmetry of the cirque suggests plucking by Neny Glacier during Red Rock Ridge glacial time. The fact that the terminus of Neny Glacier is less than a mile away, that the cirque is slightly asymmetrical, that no large end moraine is apparently present, and that in some parts of the world more work is done by local glaciers during the advancing rather than during the retreating hemicycle, all suggest that more of the cirque was cut in pre- than in post-Red Rock Ridge time (Goldthwait, 1939, pp 60-62)

It is not known how much of Neny Fjord is due to fluviatile and how much to glacial erosion. Truncated spurs are found on the north side of Red Rock Ridge (Fig. 12). They suggest that hundreds and probably thousands of feet of valley widening have resulted from glacial erosion. On the other hand, Holtedahl (1935, p 12) apparently believes that after the uplift of the peneplain in the northern part of the Palmer Peninsula dissection by glacial erosion took place without any preceding period of fluvial erosion and Priestley (1923, pp 18-20) does not believe that a long period of fluvial erosion preceded the period of glacial erosion in Victoria Land.

Erratics and a discontinuous thin veneer of moraine are common above the marine limit. Except where there has been very recent deglaciation, moraine is not found beneath the marine limit, as it has been reworked by wave action to form beach deposits. No dense, tough, and compact till was seen and this, together with the scarcity of striated stones, suggests that most of the morainal material is superglacial (Flint, 1947, pp 111-114). However, the bedrock of the area consists, in the main, of coarse-grained igneous rocks, and compact clayey till is not made from these rock types.

DEGLACIATION

Gould (1939, p 738) has nicely summarized the data on Antarctic deglaciation in the following statement: "It is the testimony of all Antarctic investigators, based upon information collected from all sides of

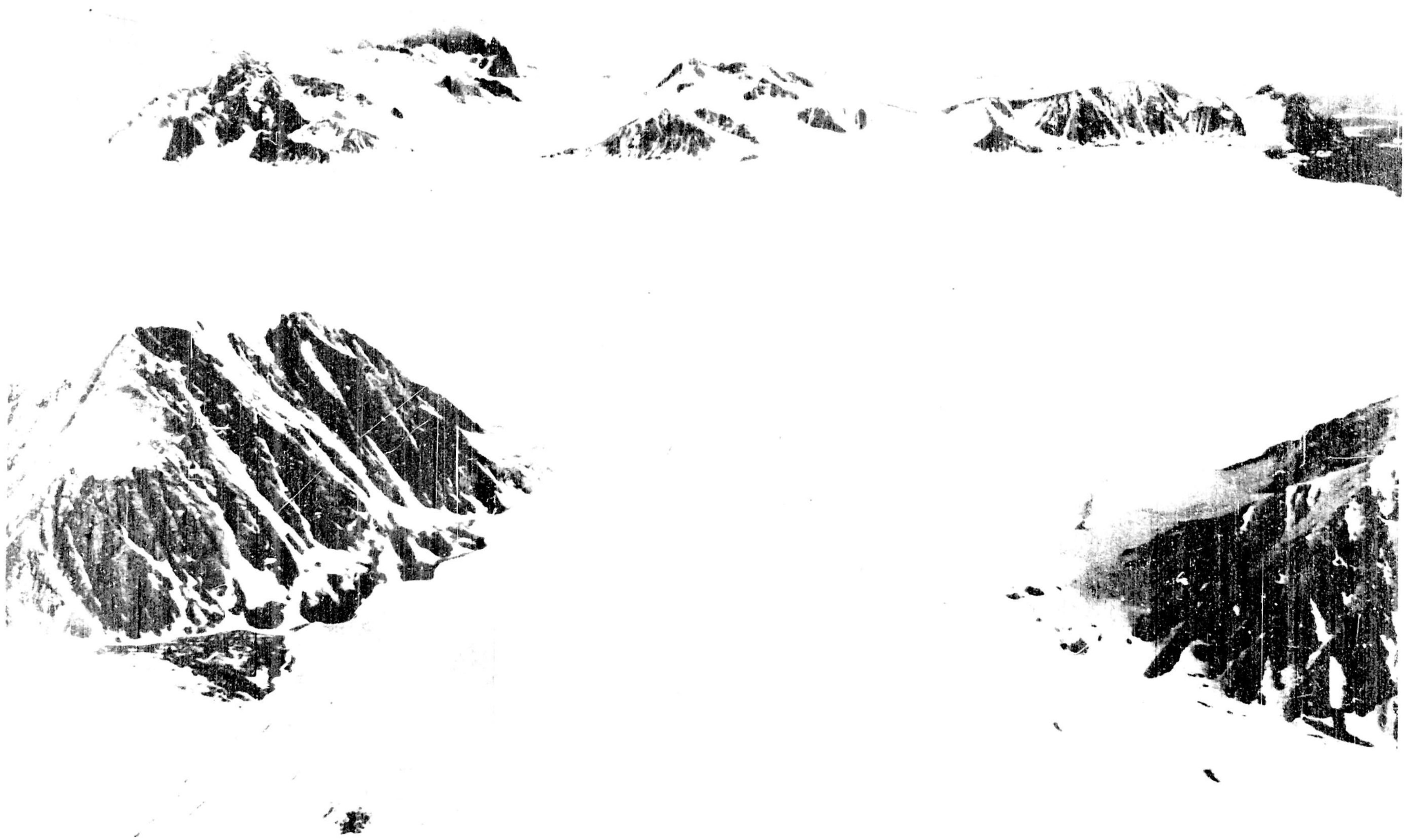

Figure 12 - Glaciated Surface on Roman Four Mt. in Foreground to Left, Valley Glacier with Lateral Moraine Next to Roman Four Mt., Truncated Spurs on Red Rock Ridge in the Distance, and Transection Glacier in Bingham Col to Left of Center in Background

the continent, that all the present glacial features, from the inland ice itself to the shelf ice masses about it, must be considered as shrunken remnants of a former, more intensive, and more extensive period of glaciation." The first expedition to winter in the Antarctic brought back data proving that the glaciers of the Antarctic were retreating (Racovitza, 1900, p 412) and subsequent investigations have substantiated this.

The deglaciation of the Palmer Peninsula has been described by Arctowski (1900, pp 479-481; 1908, pp 59-64), Nordenskjöld (1904, p 360; 1911, pp 168-174), Andersson (1906, pp 53-57), Nordenskjöld and Andersson (1905, pp 225, 466), Gourdon (1908, pp 116-121), Holtedahl (1935, pp 118-119), Fleming (1938, p 510), Stephenson and Fleming (1940, p 160), Fuchs (1951, p 413), and others. Erratics, striated blocks, moraines, roches moutonnées, polished, smoothed, and striated bedrock, and stagnant ice masses have been observed and Andersson showed that ice which must have been more than 2500 ft thick once filled the now deglaciated Gerlache Channel.

The deglaciation of Victoria Land has been described by Scott (1905a, pp 292-293, 415-417, 422-425; 1905b, pp 359-360, 364-366), Ferrar (1905a, pp 464, 467; 1905b, pp 379-380, also Sketch Map of Ice Distribution; 1907, pp 38, 81, 94), Priestley and David (1912, pp 788-791), David and Priestley (1914, pp 46, 94-98, 110-113, 262-265, 285-290, also Fig. 2, 1909, pp 285-286, 288), David (1914, pp 622-624, Figs. 5,6), Wright and Priestley (1922, pp 436-440, 221-222), Debenham (1921, pp 80-99; 1923, pp 8-9), Taylor (1914, pp 374,378,454,456,461, etc., Fig. 7, 1922, pp 63-68, 135-142), Wright (1923, p 5), Priestley (1923, pp 10,68), and Gould (1940, pp 863-864). The Ross Shelf Ice was once hundreds of feet thicker, it extended far out into the Ross Sea, and retreated 20-30 miles between 1841 and 1902. Some valley glaciers were once thousands of feet thicker.

The deglaciation of other parts of the Antarctic has been described by Hobbs (1910, pp 120-122, 1911, pp 279-281), Mawson (1914, pp 108-109), Philippi (1912, pp 51, 59-60), Warner (1945, p 84), Wade (1937, pp 593-597), Mannerfelt (1944, Fig. 6), and others. The inland ice in Kaiser Wilhelm II Land must formerly have been at least 1000 ft above its present level at Gaussberg as erratics were found at its summit.

Deglaciation is also indicated by an analysis of certain submarine topographic features. Basins appear to be present on the continental shelf southwest and west of Adelaide Island, Palmer Peninsula (U.S. Navy Dept., 1939, H.O. no. 5411) (Fig. 4). These depressions, if real, can perhaps be best explained as resulting from glaciation. Mawson (1935, pp 30-31) has written, "Everywhere beyond the margin of the continent are to be found, beneath the sea, immense terminal moraines

which outline the former maximum extension of the icecap. These built-up mounds on the sea floor are often 50 to 100 or more miles from the real land front, and they are of the order of hundreds of feet high. Off the coast of Adelie Land, the height of the main off-shore moraine is possibly to be reckoned at something of the order of 3000 feet.* It has also been suggested that both the Pennell Bank (Taylor, 1930, p 160) and the Iselin Bank (Gould, 1940, p 867) may be morainal. The significance of these submarine features is difficult to determine because little is known of their size and distribution, due to a scarcity of soundings, and because nothing is known about the material of which they are built. Geophysical surveys are in order. The writer is skeptical of the existence of a moraine 3000 ft high. Terminal moraines of this size are unknown elsewhere, and to have formed it the glacier, if grounded, might have had to be thicker than the evidence indicates it was.

In view of this record of deglaciation in many parts of the Antarctic, it is not surprising that the writer found many areas in Marguerite Bay which were the result of considerable deglaciation.

Red Rock Ridge is on the south side of Neny Fjord (Fig. 2). A small cliff glacier which reaches tidewater is found on the north side of the ridge near its western end. A steep slope veneered in part with talus is located on the north side of the ridge immediately east of the glacier. This slope flattens near the top of the ridge, and on the south side of the ridge a nearly vertical cliff several hundred feet high is found, at the foot of which there is a glacier. The country rock on the north slope, on the flat, and on all parts of the ridge immediately east of the flat is a red granite containing numerous vugs (Red Rock Ridge Granite, Nichols, 1948a, pp 2-3). It is cut by aplite, pegmatite, and trap dikes and by quartz and chalcedony veins.

Roundstones which are easily distinguished from the talus fragments were found on the north slope between 200 and 300 ft above sea level. They were rounded by water. They are not, however, elevated beach gravels, as this is above the marine limit of the area (Nichols, 1948a, p 3), and they are not now being formed, as no concentration of melt water is possible. The writer believes that they were rounded by melt water marginal to the Neny Glacier, now 12 miles eastward, and not by melt water from the nearby cliff glacier.

Still higher up on this slope, fine-grained material was found. It is too fine to have been formed by weathering. The writer believes that it is morainal material which was probably deposited by the Neny Glacier when it was more expanded than at present.

The flat is approximately 1500 ft above sea level (Fig. 13). Covering the flat, there is a felsenmeer which is composed of fragments easily

differentiated from talus because they are slightly rounded and weathered (Fig. 14). Fragments of the red granite are very abundant and others composed of whitish granite, diorite, gabbro, pyrobolite, pyroclastic and plutonic breccias, banded felsite, gneiss, and schist are present. Some of these fragments are pitted and differentially weathered (Fig. 14). One striated fragment was seen. Patches of till are also found on the flat. The red granite intrudes all of these rock types (Nichols, 1948a, pp 1-3). It might be supposed that these transported fragments were once inclusions in the red granite which were weathered out in post-glacial time. This is definitely not the case as the granite is singularly free of inclusions, no red granite was seen adhering to any of these fragments, and the slight rounding, together with the absence of the resulting weathering products, precludes this origin. The rocks of which these erratics are composed are all found in situ at the eastern end of the fjord. They were deposited on the flat by the Neny Glacier when it extended many miles west of Red Rock Ridge.

On the ridge to the east of the flat, erratics and till were found with increasing spareness up to 1700 ft (Fig. 15). The glacial limit is probably higher as the ridge is steep and there is consequently a tendency for material to move down slope, and the time available for study at this locality was limited. A figure of 2000 ft for the thickness of the ice at this point and at this time seems conservative if the depth of the water in the fjord is considered and if something is added for the thickness of the ice above the position at which the highest erratic was found. The flat is approximately 12 miles from the present terminus of the Neny Glacier. The gradient of the Neny Glacier during this stage of glaciation is not known but 100 ft per mile seems conservative. This suggests that the ice must have been approximately 3000 ft thick at the present terminus of the Neny Glacier at this time. Red Rock Ridge and Neny Island must have been nearly or completely covered with ice, Stonington Island was probably under 2000 ft or more, and the whole of the Palmer Peninsula was probably covered with a more or less continuous icecap which extended many miles westward into Marguerite Bay. This is called by the writer the Red Rock Ridge stage of glaciation.

The Terra Firma Islands, consisting of one large island and at least 9 much smaller ones, are located in Marguerite Bay at approximately 68°45'S and 67°31'W, and are about 15 miles west of the barrier on the mainland (Fig. 2). The coastline of the main island is roughly 2 miles in circumference, a barrier occurs along most of it, and on the northwest side of the island bedrock comes down to sea level. The island in large part is covered with snow and ice and a peak approximately 500 ft high is its dominant feature.

Figure 13 - The Deglaciated Flat at Approximately 1500 Feet Above Sea Level at Western Tip of Red Rock Ridge, Which is Covered with Erratics and Moraine, is Labeled F

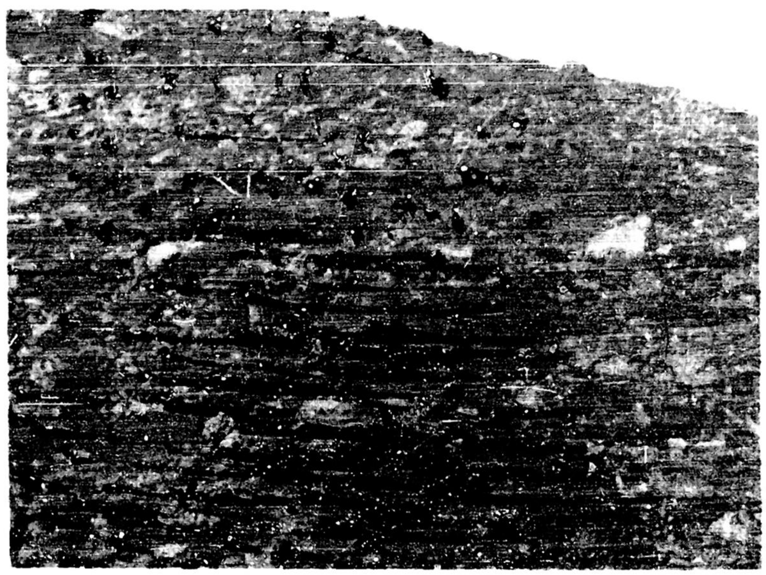

Figure 14 - Erratics at Approximately 1500 Feet Above Sea Level in the Felsenmeer on the Flat at the Western Tip of Red Rock Ridge

Figure 15 - Erratics Are Found on the Ridge in the Background up to 1700 Feet Above Sea Level, Red Rock Ridge

A relatively flat area of several acres, from which the main peak of the island has a bearing of N350°E occurs at an elevation of about 300 ft. This area was bare in the latter part of November, 1947. It is mainly a felsenmeer of fragments of many different sizes and rock types although bedrock crops out in a few places. The country rock is a dark grey pyroclastic felsitic breccia (Terra Firma Volcanics, Nichols, 1948a, p 2) cut by a few trap dikes. The breccia is composed mainly of felsitic fragments but fragments of granite, aplite, gabbro, and granite gneiss are also present.

Most of the fragments in the felsenmeer are composed of the grey pyroclastic breccia. There are in addition, however, thousands of fragments of pink granite, and diorite, gneiss, trap, felsite porphyry, and other rock types are also present. Some fragments are as much as 12 ft long. One fragment of trap with glacial striations was seen. The pink granite fragments were not weathered out from the felsitic pyroclastic breccia as they are too large and numerous and they have no felsitic material adhering to them. They were not deposited by either sea ice or icebergs, as the marine limit for this area as determined elsewhere is much lower (Nichols, 1947a), and no evidence of marine action was seen on the flat. They are glacial erratics. Pink granite similar to that of which the fragments are composed is found on the mainland and it is probably present below sea level between the mainland and the islands. During the Red Rock Ridge glacial stage, as indicated by these erratics, the mainland ice extended out to and beyond the Terra Firma Islands. Fragments of pink granite and of other rock types were plucked from outcrops on the mainland and from ledges between the mainland and the islands and were deposited on the flat. No time was available to climb the 500-foot peak on the island and so the upper limit of glaciation was therefore not precisely determined. The ice must have had considerable thickness above the flat, however, in order to be able to drop erratics on it 12 ft long; and as it rested on the bottom of the ocean, it must have been at least 500 feet thick in this area. It undoubtedly extended 5 or more miles beyond the islands, and it was probably at this time 2000 or more feet thick at the site of the present barrier on the mainland (Fig. 16). The erratics are clean, fresh, and unweathered. The roundstones on the upper parts of the elevated beaches on Stonington Island, on the other hand, are fretted, roughened by exfoliation, and accumulations of spalled fragments often surround them (Nichols, 1947a). The elevated beach gravels on Stonington Island are much younger than the erratics, as the beach gravels are only a fraction of a mile from the Northeast Glacier, whereas the erratics are many miles from the glacier which deposited them. The erratics on Terra Firma Island are less weathered because: First, the erratics until very recently may have been covered by the local icecap. Second, the erratics, being farther south and higher, may be covered with snow

for a greater part of the year than the beach gravels. Third, at the Terra Firma Islands the freezing point may not be crossed as often, so that frost action may not be as important a rock-shattering agent as at Stonington Island. The local icecap on the main Terra Firma Island was not a very effective erosive agent as it did not remove the erratics which were deposited on the flat during the Red Rock Ridge glacial stage.

Till is found on the flat. Moss grows on it, as it holds moisture. Rude polygon boden 6 to 9 ft in diameter are found in places on the till. These were the only polygon boden seen in the Antarctic by the writer, although polygonal structures were also observed by Taylor (1922, pp 45-46) in many places in the McMurdo Sound area. Their scarcity is due to the lack of fine-grained mantle rock, to the recentcy of deglaciation, and to the continuously low soil temperatures resulting from the more or less constant snow cover, the low, free-air temperatures, and the small amount of solar radiation.

No erratics were seen on one of the small Terra Firma Islands. They may have been removed by wave action, by a local icecap, or by gravitational processes as the island has steep slopes and only a small summit area.

An island is located in Marguerite Bay from which the southern tip of Adelaide Island has a bearing of approximately N21°E and from which it is between 10 and 15 miles distant. Black argillites, conglomerates, and sandstones cut by felsite and felsite porphyry dikes occur. Excellently formed and preserved glacial striations oriented N60°E - N240°E were found on the argillites. The mainland is more than 50 miles away to the northeast. There is another island a short distance away on which black argillites and conglomerates cut by granite and porphyritic trap dikes occur. Glacial striations oriented approximately N72°E - N252°E are common and transported boulders of gabbro and granite are present. The striations on these islands could have been formed by either a local icecap or by an extension of the mainland ice. Deglaciation has taken place in either case. The excellent development of the striations and the close correspondence of alignment on the two islands suggest that they are due to mainland ice, which at this time extended more than 50 miles beyond its present position, buried these islands, and terminated even farther seaward. The gabbro and granite boulders could have been transported by the mainland ice or by icebergs or sea ice as raised beaches are found on the islands.

Six or more small islands are located approximately 50 miles west of Stonington Island. A small icecap covers part of one of them. The country rock is gabbro and diorite and it is cut by trap, aplite, granite, and felsite porphyry dikes. Smooth glaciated surfaces, undrained

depressions in bedrock, and glacial striations, grooves, and trenches are present. It is not known whether these features have been formed by a local icecap or by an extension of the mainland ice. In either case, deglaciation is indicated. Boulders of felsitic pyroclastic breccia and other rock types not found on the islands are present in elevated beaches. They were transported and deposited here either by sea ice, icebergs, or the extended mainland ice.

Roman Four Promontory[1] projects about 1-1/2 miles southwestward into Neny Fjord. It is approximately 1 mile east of Neny Island and is about 2700 ft high (Fig. 2). A valley glacier with a prominent lateral moraine on its southern edge lies immediately northeast. Above the glacier, at approximately 1300 ft above sea level, there is a smooth, flattish bedrock surface which contrasts sharply with the steep cliffs below it. This smooth surface continues upwards with increased steepness toward the summit. The summit is a small, smooth, round dome. To the southwest there is a ridge of lower, saw-toothed peaks. These features can be seen clearly from Stonington Island and they are shown in Figs. 17 and 18. The writer believes that the smooth, flattish surface near 1300 ft and the roundish summit are due to glacial erosion which took place during the Red Rock Ridge glacial stage. The surface of the ice in this area at this time must have been 3000 or more ft above the present sea level. Following deglaciation, parts of the glaciated surface were destroyed by the headward growth of the cliffs, some of the saw-toothed ridge was formed, and talus accumulated at the foot of the promontory.

On Neny Island, there are a lower, western and a higher, eastern peak (Fig. 2). The eastern peak is approximately 2000 ft above sea level. There is a northward sloping col between them at about 1300 ft or more which, when viewed from Stonington Island, appears to be U-shaped. Bedrock at the bottom of the col appears to be smooth, elsewhere in it and on the peaks it is rough. A mantle of angular fragments in places veneers the bedrock in it. This col may be due to pre-glacial erosion and to a glacier which moved through it during the Red Rock Ridge glacial stage. The angular fragments are probably due to glacial deposition and to post-glacial weathering.

Similar features were seen on an unidentified island which is south of Adelaide Island.

A well-formed, prominent U-valley in which no glacial ice is visible is found just east of Bingham Col and northwest of Neny Fjord Thumb

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[1]Also called Roman Four Mountain.

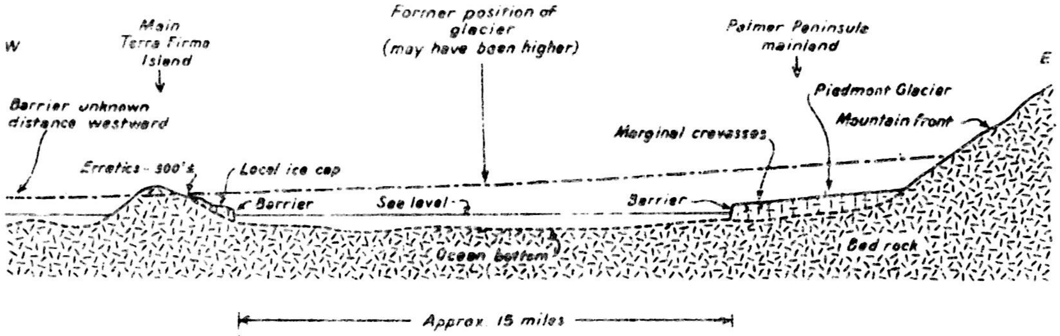
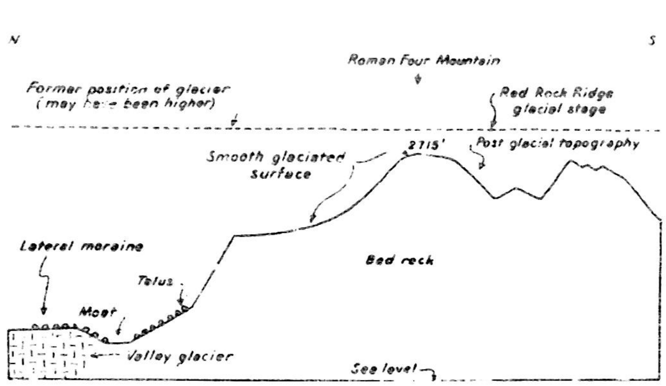


Figure 16 - Diagram Showing the Former Maximum Extension of the Ice in the Area Around Terra Firma Islands

Figure 17 - Diagrammatic Sketch Showing the Glaciated Surfaces on Roman Four Mt. and the Upper Limit of Glaciation in this Area



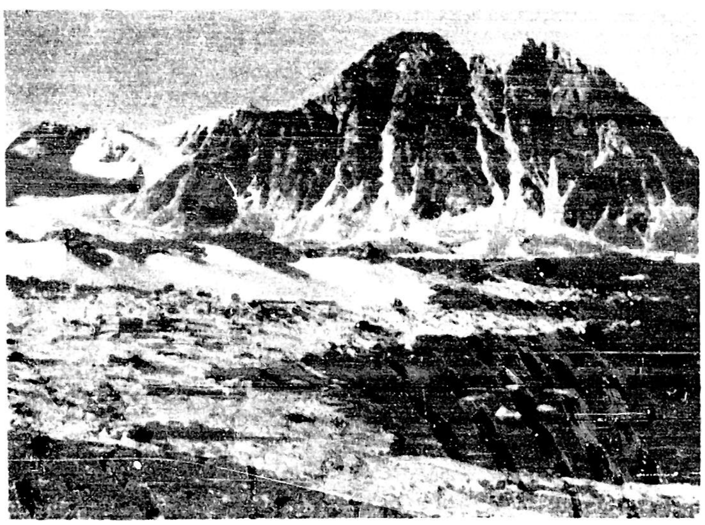


Figure 18 - The Glaciated Surfaces on Roman Four Mt. in Background, and Snowdrift Ice Slabs and Elevated Beaches on Stonington Island in Foreground

Figure 19 - U-Valley to the Northwest of Neny Fjord Thumb (Unofficial Name) is on the Right

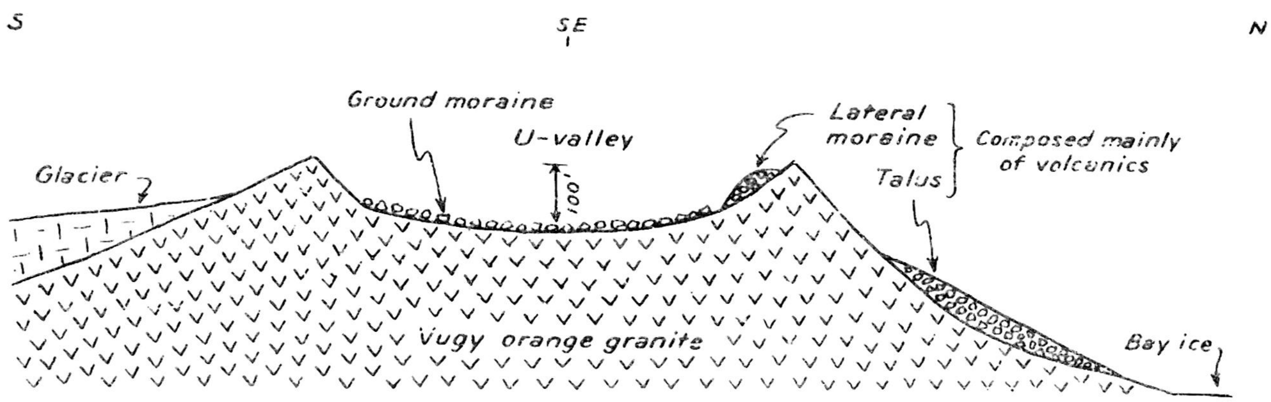


Figure 20 - Diagrammatic Transverse Cross Section of the U-Valley to the Northwest of Neny Fjord Thumb (Unofficial Name)

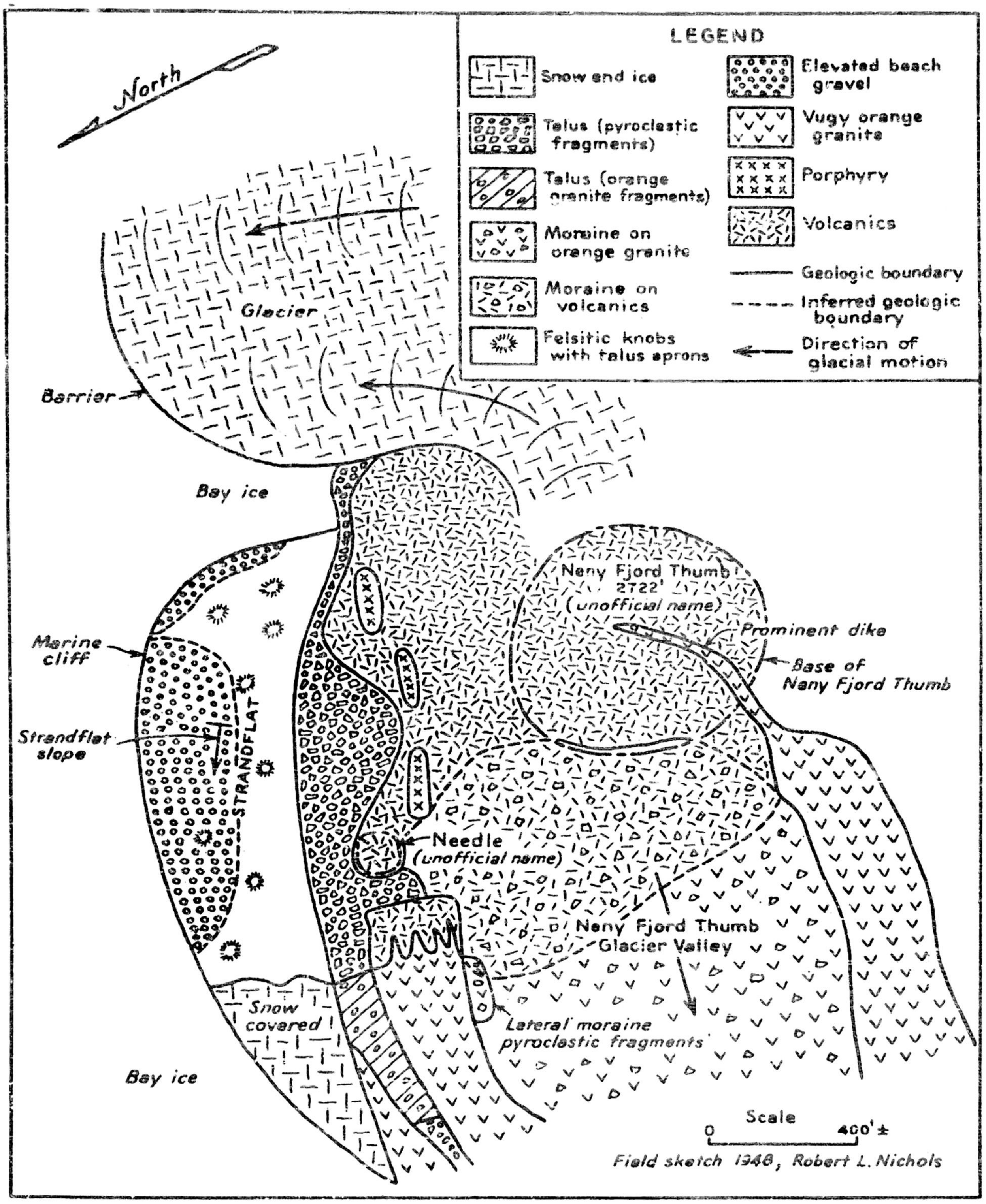


Figure 21 - Geologic Map of the Area Around Neny Fjord Thumb (Unofficial Name)

(unofficial name) (Figs. 2, 19). The outer slope of the ridge, on the north side of the valley, extends below the valley and down to the bay ice, and that on the south side extends down to a glacier which in places is below the bottom of the U-valley. As the northwestern end of the valley hangs above the glacier in Bingham Col, the bottom of the valley is, therefore, perched above the surrounding country. Both ridges are composed of a vuggy, orange granite (Red Rock Ridge Granite, Nichols, 1948a, pp 2-3) and Neny Fjord Thumb (unofficial name), which is at the head of the valley, is composed of gray volcanic rocks (Terra Firma Volcanics, Nichols, 1948a, p 2) (Figs. 20, 21). A felsenmeer of large, unweathered, morainal fragments covers the bottom of the valley. A well-preserved lateral moraine composed of the gray volcanics and resting on the vuggy granite is found on the north side of the valley not far below the crest of the ridge (Figs. 20, 21). No recessional or terminal moraines were found. A talus slope is located on the outer side of the ridge on the north side of the valley. The fragments on the surface at the eastern end of the slope are composed mainly of vuggy, orange granite, whereas those at the western end are mainly gray volcanics (Fig. 21).

During the Red Rock Ridge glacial stage, ice so completely blanketed this area that perhaps only the highest peaks were nunataks. Following a period of extensive reduction in the thickness and area of the ice, a small glacier occupied the valley. In its early stages this glacier completely filled the valley and volcanic fragments carried by it rolled down the outer side of the western end of the northern ridge. At this time, apparently no glacial ice was in existence on this part of the ridge and a talus slope composed mainly of gray volcanic fragments resting on an orange, vuggy granite was formed. Volcanic fragments from the glacier also rolled down the outer side of the eastern end of the northern ridge, but these were either removed by glacial ice or were buried by granitic fragments derived from the ridge itself at a later date. At this stage, the glacier flowed northwestward and cascaded downward to lower levels at the northwest end of the valley, and it also streamed northeastward around both sides of the Needle (unofficial name) (Fig. 21). At a later stage, when the glacier had been somewhat thinned, the lateral moraine was deposited (Fig. 20). The fact that the valley hangs above the glacier in Bingham Col prevented the formation of a terminal moraine in the valley. At a still later date, the felsenmeer was completed by the deposition of en-glacial and super-glacial ground moraine. This took place only a short time ago, as the fragments are not weathered and they are not surrounded by aprons of spalled fragments. The U-valley, the lateral moraine, the ground moraine, and the talus all indicate, therefore, a recent deglaciation of the area.

A highland icecap resting on the uplifted erosion surface is located above an imposing bedrock cliff on the north side of Neny Glacier. An ice slope sweeps downward for hundreds of feet from the foot of the bedrock cliff to the edge of Neny Glacier below. Several elevated patches of moraine are found on the slope. The moraine was probably deposited when the slope was higher than at present. It stands high because it has inhibited the wastage of the ice on which it rests. The patches of moraine perhaps indicate a recent thinning of the ice and lowering of the slope from between 15 and 20 ft (Fig. 22).

A small bedrock island near Moraine Point (unofficial name) (Fig. 2) which is smooth and rounded, veneered by a small quantity of spalled fragments, and a short distance from the mainland glacier, has recently been deglaciated. On the mainland not far away are areas of bare, unweathered granite on which erratics and moraine were deposited (Figs. 23, 24). The surface of the glacier which deposited these erratics and moraine is now a few score feet below them and a thinning as well as a terminal retreat occurred (Fig. 25).

Roundstones resting on and surrounded by angular fragments are found about 20 feet above sea level at Moraine Point (unofficial name) (Figs. 26, 27). A sloping bare bedrock surface is found between them and the bay ice. The angular fragments are mainly morainal, although some may be due to frost action following deglaciation. The marine origin of the roundstones is proved by the following: First, they are much too well rounded to be glacio-fluvial roundstones, as concentrated melt water has probably never been abundant in this area. Second, they appear to be more abundant nearer the ocean. The lack of broken and abraded roundstones indicates that the glacier did not readvance over an elevated beach and later deposit both the angular fragments and the marine roundstones, but that it deposited the angular fragments and later the roundstones were thrown by wave action onto the moraine. The sloping bedrock surface is bare in part, at least, because of wave washing. The height of the roundstones above the bay ice and their distance from it suggest that they were deposited when the sea was higher than at present. If this is correct, the moraine has some antiquity as it was deposited at a still earlier time.

Above Moraine Point (unofficial name), where the head of the glacier and the mountain bedrock slope meet, there is a depression in the surface of the glacier. It may be due to the local configuration of the bedrock on which the glacier moves, to a recent local decrease in snow avalanching, or to other local factors. However, if this depression is found everywhere, at the junctions of the glaciers and their headwalls, it would strongly suggest an amelioration in climate and the beginning of a period of glacial thinning and deglaciation. Unfortunately, there was no time to study this.

Figure 22 - The Crevassed Neny Glacier, Transverse Ridge at the Terminus of Neny Glacier, Neny Glacier Island (Unofficial Name), Raised Moraine on an Ice Slope in the Foreground to the Left, and Folded Bay Ice and Synclinal Ponds

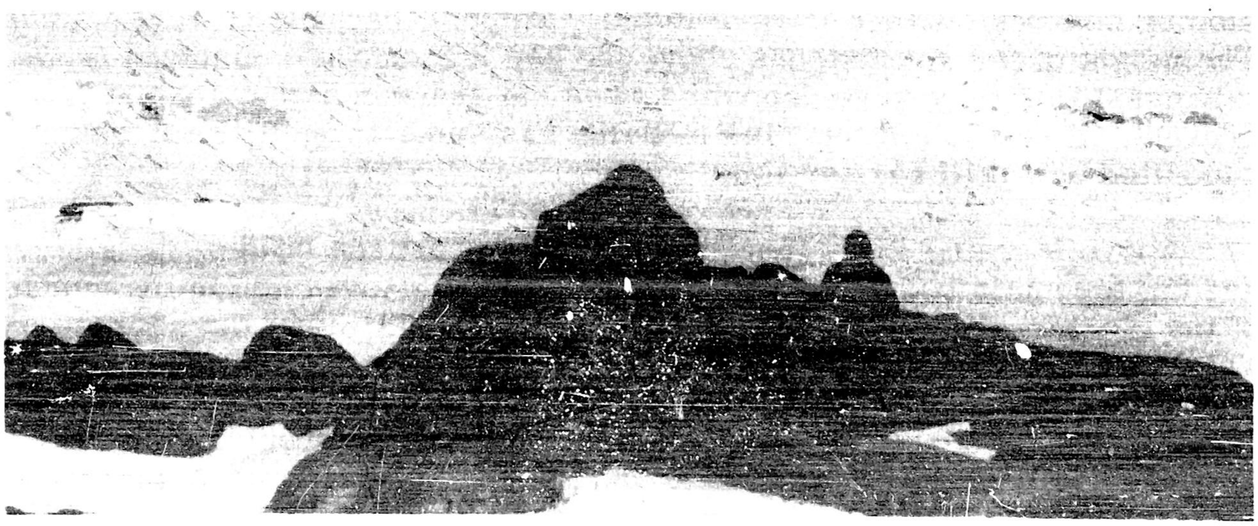


Figure 23 - An Erratic at Moraine Point (Unofficial Name)

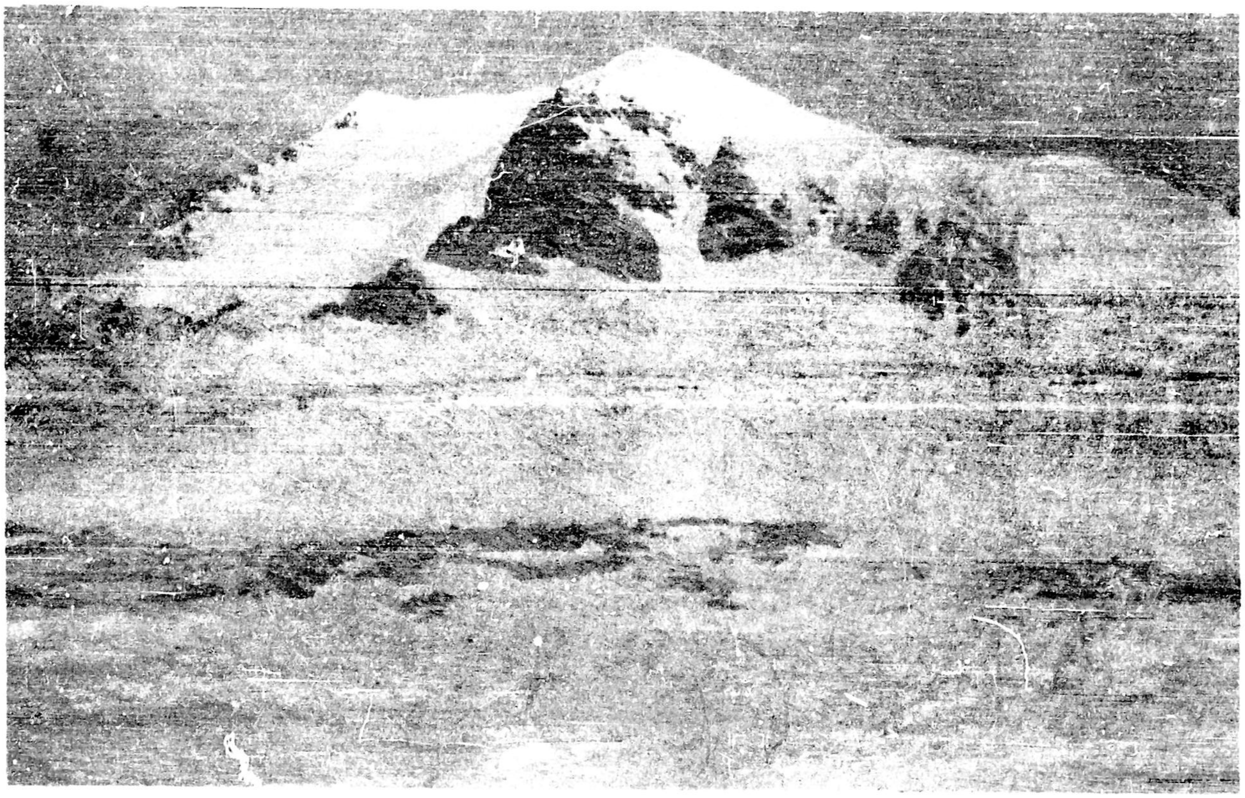


Figure 24 - Recently Deglaciated Area at Moraine Point (Unofficial Name)

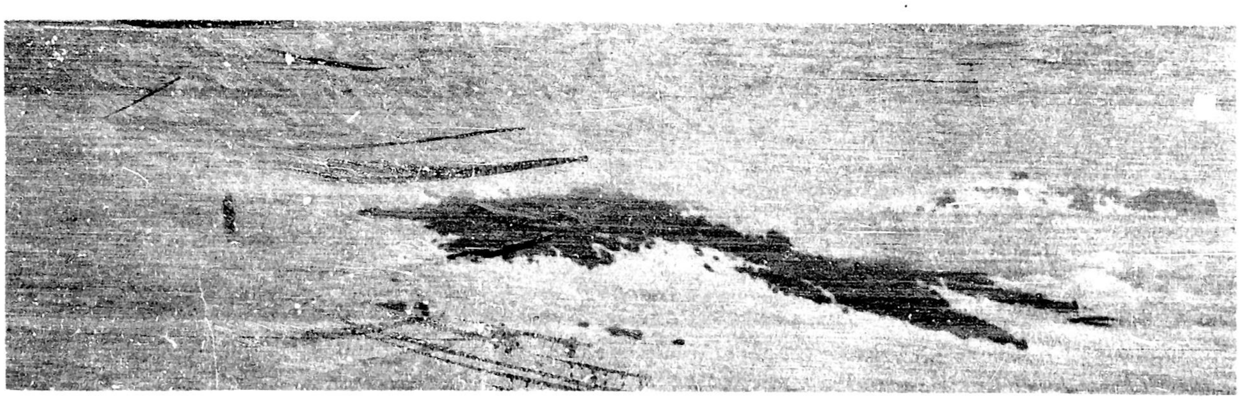


Figure 25 - Morainal Material at Moraine Point (Unofficial Name)

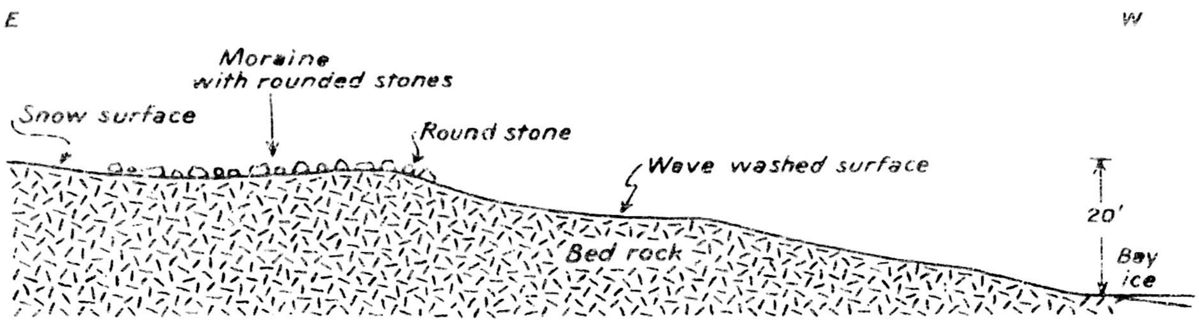


Figure 26 - Diagrammatic Sketch Showing Elevated Marine Roundstones, Moraine, and Wave-Washed Surfaces at Moraine Point (Unofficial Name)

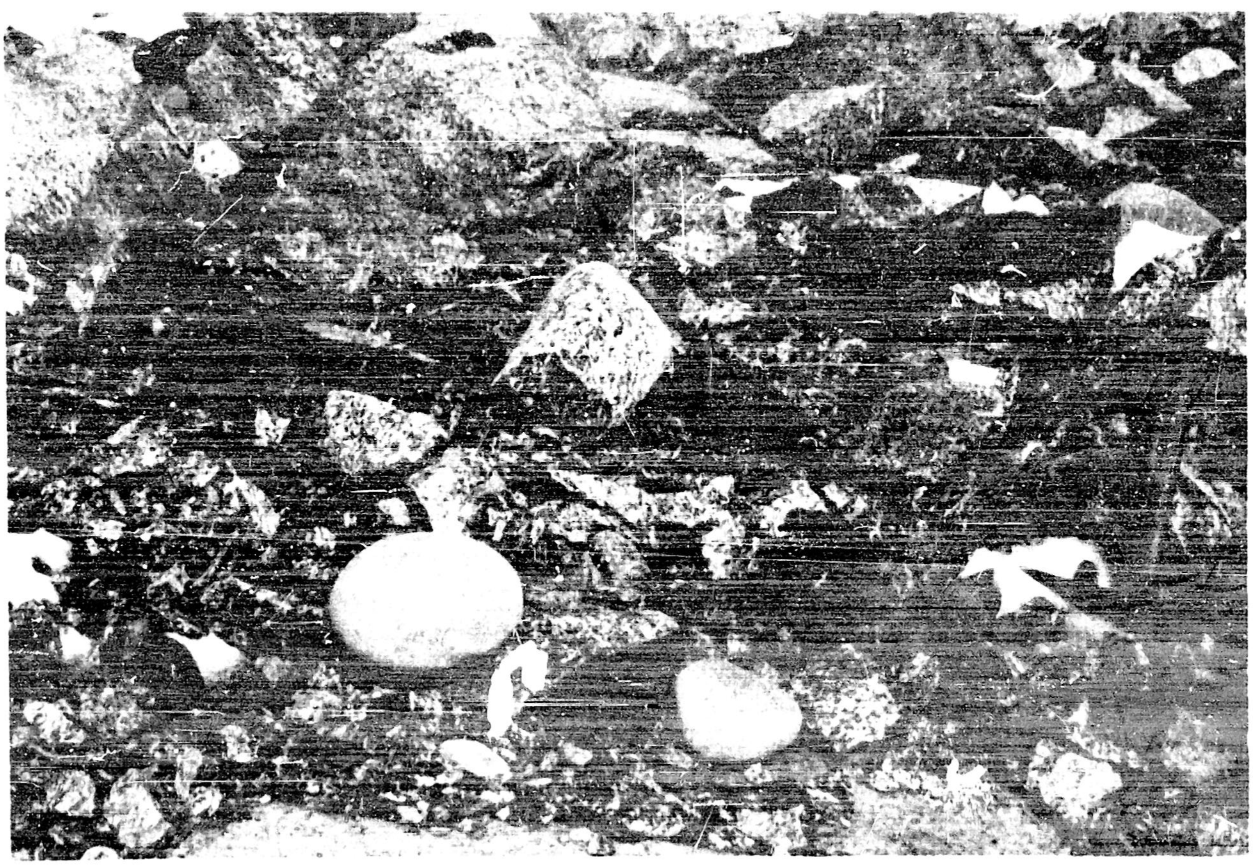


Figure 27 - Moraine and Elevated Beach Gravels at Moraine Point (Unofficial Name)

Many roundstones are found up to 480 ft above sea level on the south side of Black Thumb Mountain. Some are more rounded on the top than on the bottom and some have fine-grained material beneath them. No ridges, cusps, or other beach features were observed. It seems likely that the rounding was due to melt water and that this is a small fluvio-glacial deposit. The fact that some of the roundstones are better rounded on the top suggests that the movement of finer material over and around them was important in the rounding. The material is not now being deposited and it indicates, therefore, a small amount of deglaciation.

A lateral moraine is found near Black Thumb Mountain. Its location proves that the nearby glacier has recently retreated.

A valley glacier reaching tidewater and having a prominent lateral moraine on its southern edge lies immediately northeast of Roman Four Promontory (Figs. 28, 29). The moraine, consisting mainly of large fragments, must be several feet thick as the glacier is completely buried by it. Morainal material is being dropped into the bay and a submarine recessional moraine is being formed. As far as is known, it has not built itself up above sea level. This suggests that the terminus of the glacier has been at its present position only a short time and that it has recently been retreating.

Blocky moraine extending down to sea level is found close to the northern edge of the terminus of Neny Glacier. The moraine was not deposited beneath sea level and later elevated, as no offshore elevated marine deposits are associated with it and no elevated beaches are found near it. Deglaciation has been so recent here that no uplift has occurred since the moraine was deposited.

The Refuge Islands, which are about 5 miles south of Red Rock Ridge, are considerably less than a mile from land ice. The presence of smooth, roundish outcrops on one of these islands, together with the scarcity of spalled rock fragments, indicates that they have been recently deglaciated.

Data on the remarkable rate of retreat of the ice shelf in King George VI Sound from 1940 to 1949 is furnished by the observations of Ronne and Fuchs. Eklung Island is a rocky nunatak more than 1000 ft high in the southwestern part of King George VI Sound. When Ronne and Eklund visited the island in December, 1940, the edge of the ice shelf in King George VI Sound was approximately 30 miles to the northwest (Ronne, 1945, map 1; 1948, Fig. 1). Fuchs and Adie visited the island in November, 1949 and found bay ice at its foot. The edge of the ice shelf had, therefore, retreated approximately 30 miles in this area in this 9-year interval. With regard to this surprising retreat, Fuchs (1951, p 411, Fig. 4) wrote, "To our surprise we had to descend some 30 feet (from the

Figure 28 - Valley Glacier with Prominent Lateral Moraine Immediately North of Roman Four Mountain. Barrier of Northeast Glacier to Left

Figure 29 - Lateral Moraine on the Valley Glacier Immediately North of Roman Four Mountain. Neny Island with Fringing Glacier on Left and Talus Slopes on Right in the Distance

ice shelf) to a lower level of ice two and a half miles before we reached the island (Eklund). We found that we had descended once more to the sea ice and that the shelf ice had broken back for 30 miles from the position in which Ronne and Eklund had found it in 1940. It was therefore scarcely surprising that we found Eklund Island to be the largest of ten islands where only one was supposed to exist. Around some of these islands the sea ice was only 2 in. thick."

The edge of the ice shelf at the northern end of King George VI Sound is likewise rapidly retreating. The eastern side of the barrier was approximately 12 miles south of Cape Jeremy when mapped by Stephenson (1940b, p 232) in 1937. The Falkland Islands Dependencies Survey found in 1948 that the western end had retreated between 25 and 30 miles in this 11-year interval and that the eastern end had retreated about 15 miles (Fuchs, 1951, p 405; Fig. 2). Ronne (1948, p 362) had also noted this retreat. Concerning it he wrote, "Our plane flights . . revealed . . . that the face of the shelf had moved back 35 miles in seven years." It would be interesting to know whether the shelf ice is getting thinner. The presence of a zone of fresh rock below weathered rock, on the cliffs at the edge of the Sound, might be used to determine the amount.

If these rates of retreat are continued, the bulk of the ice shelf in King George VI Sound will have disappeared in a few hundred years.

A comparison of Figure 30, a photograph of Stonington Island and the Northeast Glacier taken by the U. S. Antarctic Service Expedition in November, 1940 with Figure 31, a photograph of the same area taken by the Ronne Antarctic Research Expedition in April, 1947 indicates that the Northeast Glacier has retreated measurably in this 6-1/2-year interval. CDR Finn Ronne believes that the Northeast Glacier in places near Stonington Island has retreated more than 200 feet in this interval.[1] A comparison of photographs taken of Neny Glacier in 1940 and 1947 (Figs. 32, 10) suggests that the south side of Neny Glacier has retreated hundreds of feet in this interval. These four photographs, when compared with photographs yet to be taken of these areas, should prove valuable to the future students of the deglaciation of this area.

STRANDFLATS

A well-developed strandflat is located along the south side of Neny Fjord at the foot of Neny Fjord Thumb (unofficial name) and the Needle (unofficial name). It is bounded on the north and east by the waters of

[1] Personal communication from Commander Finn Ronne.

Figure 30 - Aerial Photograph Showing the Relation of the Barrier of the Northeast Glacier to Stonington Island in November, 1940

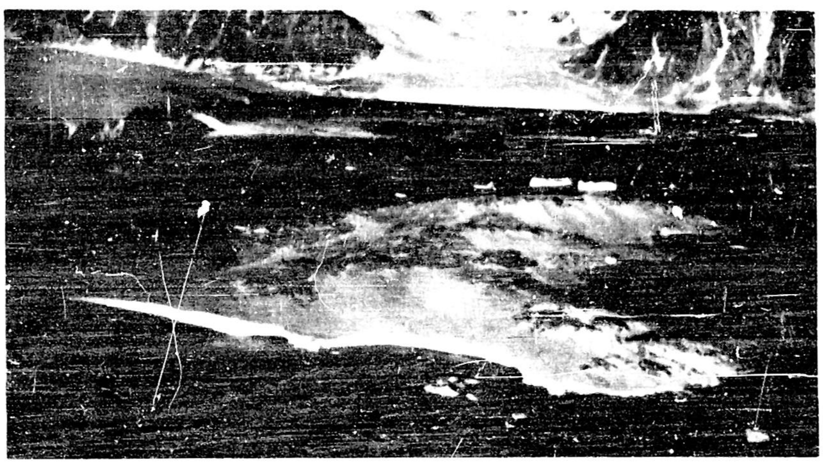


Figure 31 - Aerial Photograph Taken in April, 1947, Showing the Relation of the Barrier of the Northeast Glacier to Stonington Island

Figure 32 - Aerial Photograph Showing the Position of the Terminus of Neny Glacier in November, 1940

the fjord, on the south by talus slopes and bedrock cliffs, and to the west it gets narrower and terminates against bedrock slopes. It is about 1500 ft long, over 400 ft wide for most of its length, and is in places as much as 20 ft above sea level (Fig. 33). It is highest at the southeast and from there it slopes gradually to the northwest where it is approximately at sea level. Elevated beach gravels in places veneer the strandflat and felsitic knobs dot its surface (Figs. 34, 35).

There is a cliff along the southeastern end of the strandflat which is about 1000 ft long and from 7 to 20 ft high. In places it is cut in bedrock veneered thinly with till and beach gravel and elsewhere it is cut in sandy till which is usually veneered with beach gravel (Fig. 36). The strandflat has resulted, therefore, from the erosion of bedrock and the deposition of till and beach gravel. The foot of the cliff when seen in January was covered by snow and bay ice.

The position of the bay ice and the small amount of talus found along the cliff prove that waves and shore currents are now acting along its base. Beach sands containing comminuted shells were seen veneering the cliff at one place. The material was deposited there by wave action. As it could not remain on the cliff long, however, it proves that waves are now acting at its base and in addition that there is also a beach along at least a part of the cliff.

The cliff cut in the sandy till is marine. It might be thought that this cliff was due to a stillstand of the sea at or near its present position. Elevated beach gravels at many places around Marguerite Bay come down to sea level in a smooth, gently-sloping plain. However, if any significant stillstand of sea level had taken place at or near its present position, high beach ridges, marine cliffs cut in beach gravels, or flat plains resulting from a prograding of the beaches should be found at the strandline, depending upon the supply of material available for the formation of beach deposits. In view of this and because low cliffs cut in sandy till can be rapidly formed by waves and shore currents, the writer does not believe that this till cliff indicates any significant stillstand of sea level at or near its present position. The presence of beach gravels on top of the till and 20 feet above sea level indicates that the cliff was formed as sea level dropped something less than 20 feet with respect to the land. The bedrock cliff, on the other hand, if formed by marine action would need much more time for its formation and would indicate a stillstand. In view of the above, however, the writer believes that the cliff was glacially formed, that till was deposited in front of it, and that this till was removed by wave action. The bedrock cliff has been brought to the strandline by marine processes, but is not itself the result of marine erosion. It is a contraposed cliff (Clapp, 1913).

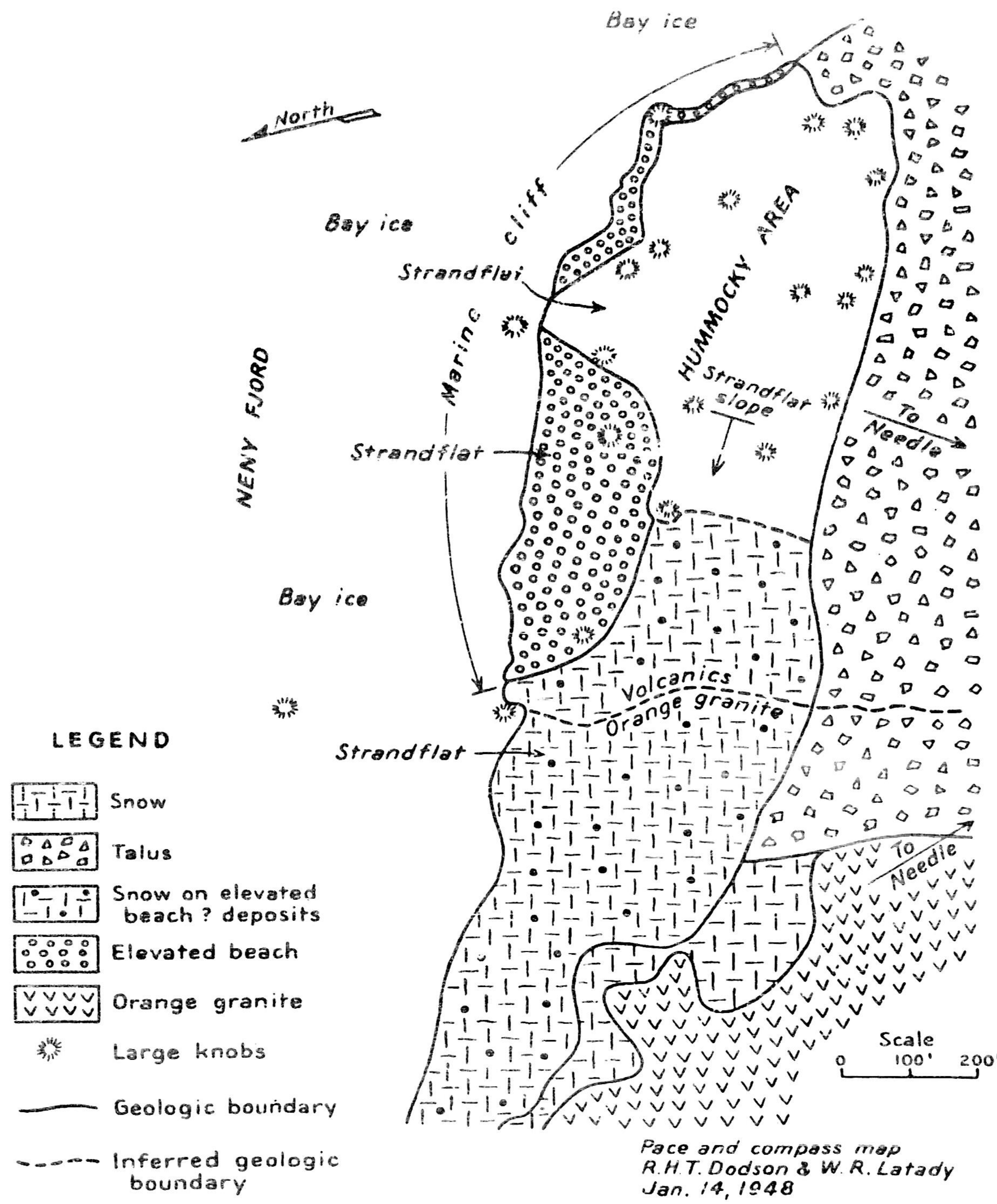


Figure 33 - Geologic Map of the Strandflat Near Neny Fjord Thumb (Unofficial Name)

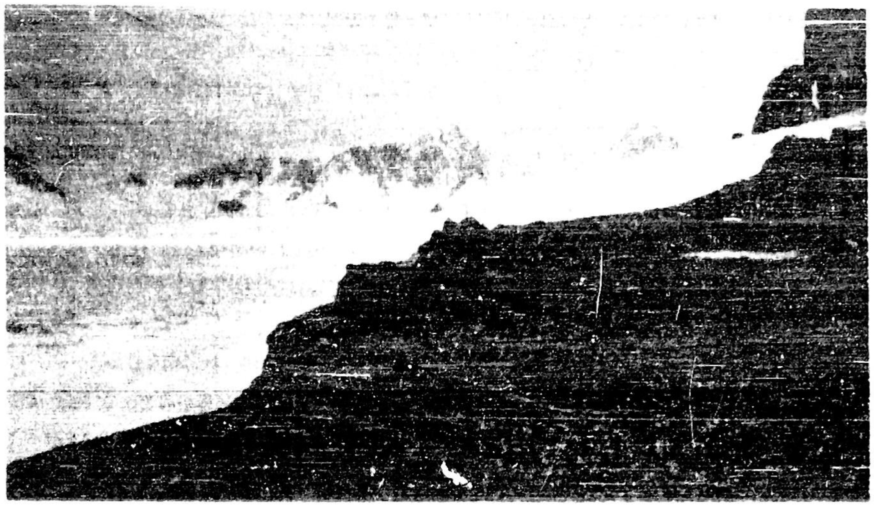


Figure 34 - Elevated Beach Gravels, Knobs, and Mushroom Rocks on the Strandflat, Neny Fjord Thumb (Unofficial Name)

Figure 35 - Knobs Scattered on the Strandflat and Bay Ice Near Neny Fjord Thumb (Unofficial Name)

Figure 36 - Marine Cliff Cut in Till at the Strandflat Near Neny Fjord Thumb (Unofficial Name) in Foreground, and Talus Progressively Burying the Strandflat in Background

Beach gravels are found almost everywhere along the upper part of the cliff. They rest on till, are up to 4 ft thick, and are as much as 20 ft above sea level (Figs. 34, 37). These gravels are composed mainly of felsite, and also of porphyry, granite, and gneiss. The felsite, because of its pronounced cleavage, is only slightly rounded. Till was the source of most of these gravels. The knobs were also sources, and talus and bedrock may have been additional sources. The distribution of the beach gravels on the strandflat is shown in Figure 33.

The felsitic knobs vary greatly in size. One about 20 ft high and 30 ft long was measured. Others even larger were seen. The largest are at the southeast end of the strandflat and they decrease in size toward the northwest. Three knobs are found off-shore from the cliff. When seen in January, they were surrounded by bay ice. Small ponds are found in the depressions between the knobs. Talus aprons surround the knobs (Fig. 38). The closely jointed felsite of which the knobs are composed facilitates the formation of the aprons. The talus is composed of angular fragments which are easily differentiated from the surrounding subrounded beach gravels. It usually forms a much flatter slope than normal talus (Fig. 37). This is probably due to the fact that many of the fragments may have fallen on a snow slope and perhaps to the existence of ground ice in the interstices between the fragments. A few debris cones were seen and here the original knobs are completely buried in their own debris (Taylor, 1922, pp 69-73). The formation of talus aprons because of the weathering of the knobs has also resulted in the origin of mushroom rocks, pinnacles, and oddly shaped knobs (Fig. 39).

These knobs have been transported from felsitic outcrops and deposited on the strandflat. This is proved by the following: First, the attitude of the flow lines in the felsite of which the knobs are composed changes from knob to knob in such a way as to suggest that they are not in place. Second, the strandflat was glaciated during and after the Red Rock Ridge glacial stage. If the knobs are in place, the topography of the strandflat would be too rough and irregular to have resulted from glaciation. The knobs must have been deposited, therefore, on a glaciated surface. Third, large blocks not in place are exposed in the till cliff on the seaward side of the strandflat. These blocks suggest that the knobs may not be in place. Fourth, the knobs can easily be accounted for by having been transported and deposited by glacial action or having been transported from bedrock cliffs down snow and ice slopes.

It might be supposed that the knobs broke off as fragments from the nearby cliffs of Neny Fjord Thumb (unofficial name) and the Needle (unofficial name) and rolled down earlier and existing talus slopes. The following indicate that this is unlikely: The felsite is so closely jointed that large fragments falling from the cliffs would probably break up into

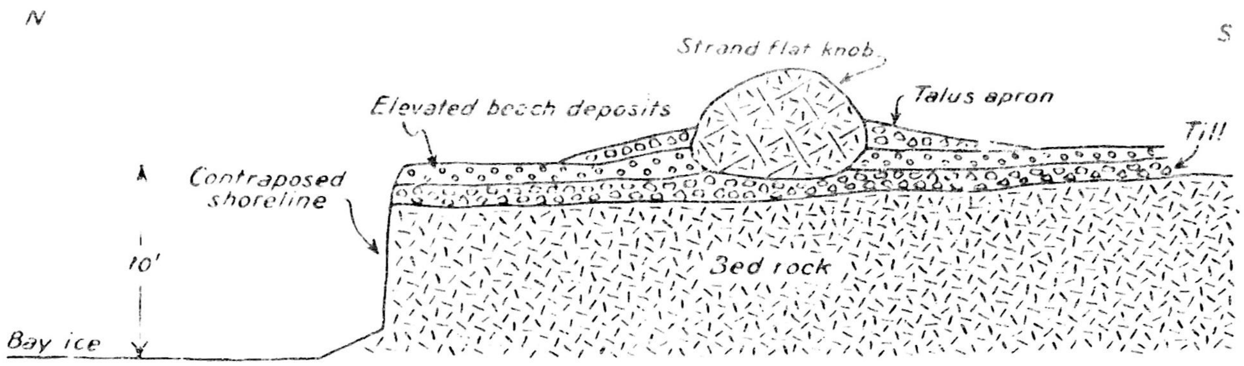


Figure 37 - Diagrammatic Sketch Showing the Relation of Bedrock, Till Elevated Beach Gravels, and Strandflat Knob at the Strandflat Near Neny Fjord Thumb (Unofficial Name)

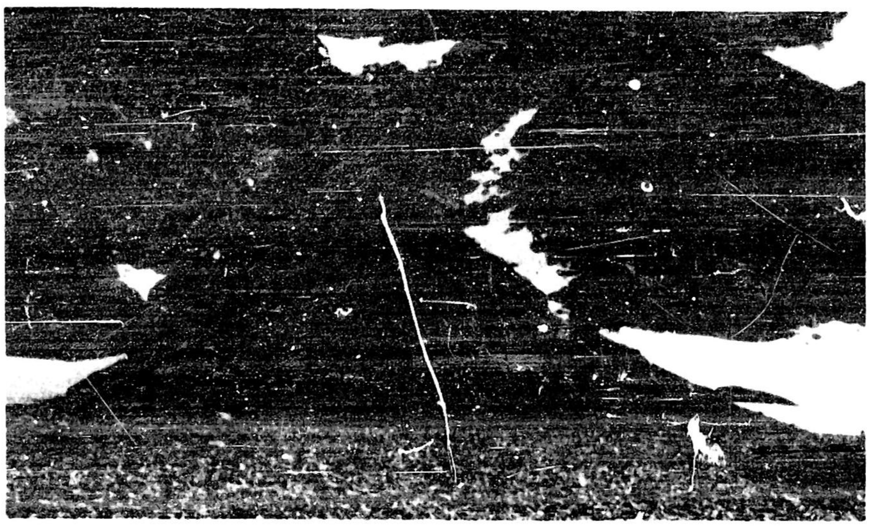


Figure 38 - A Knob Surrounded by a Talus Apron and Elevated Beach Gravels in the Foreground on the Strandflat Near Neny Fjord Thumb (Unofficial Name)

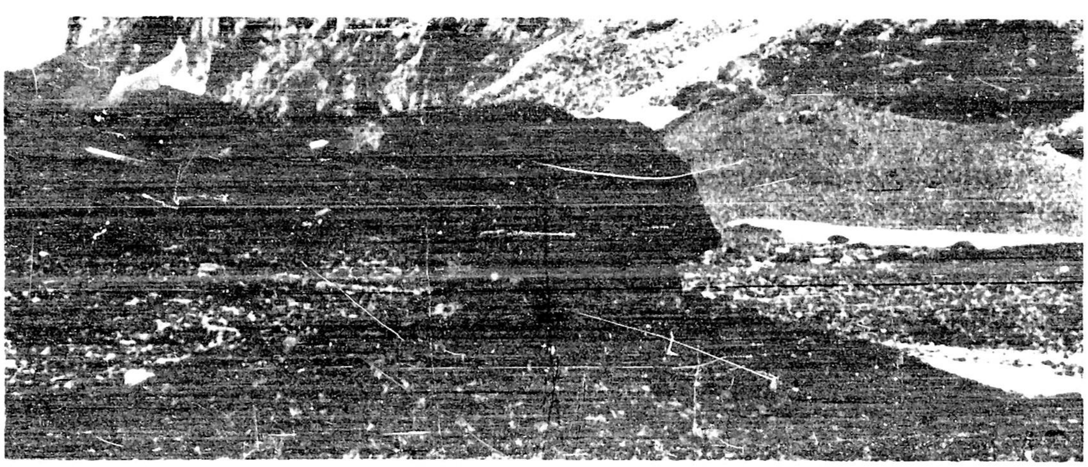


Figure 39 - Mushroom Rock and its Talus Apron on the Strandflat Near Neny Fjord Thumb (Unofficial Name)

masses much smaller than some of the knobs. Knobs are found more than 700 ft from the foot of the talus. It is very unlikely that fragments which rolled down the present talus slopes could have gained enough momentum to move across hundreds of feet of the relatively flat strandflat. If the fragments had reached the strandflat when the talus slopes were smaller, it would have been still more difficult for them to move far enough across the strandflat. Fragments falling from the cliffs before the talus formed would have come to rest relatively close to the base of the cliffs. As the talus slopes increased in size, the fragments would, in general, have had enough momentum to move farther and farther out across the strandflat. Because of this, earlier knobs would have obstructed the movement of later knobs, and knobs would have piled up one behind another. No such distribution exists. No grooves or trenches were seen in the beach gravels which were formed by the sliding and rolling of the knobs across them.

The knobs must have been in existence long enough so that their talus aprons could form. Felsitic morainal fragments deposited near Neny Fjord Thumb (unofficial name) by the Bowl Valley Glacier (unofficial name) are found in the Bowl Valley (unofficial name). Although they are lithologically similar to the knobs, they are too young to have talus aprons around them. This suggests that the knobs were deposited on the strandflat before the Bowl Glacier (unofficial name) disappeared.

Nothing was seen along the marine cliff which indicated whether the knobs rest on beach gravels or till. However, the size of the talus aprons, the fact they they did not break off from nearby cliffs and roll out onto the strandflat, and the fact that large felsitic fragments are found in the till make the writer believe that they have some antiquity and that they rest on till and are surrounded by beach gravel (Fig. 37).

An analysis of the truncated spurs of Neny Fjord indicates that in places it has been widened hundreds of feet by glacial erosion. It is, therefore, obvious that the strandflat was not formed in pre-glacial time. The fact that till veneers the bedrock platform proves that it is not the result of post-glacial marine erosion. The deposition of the beach gravels which veneer the till undoubtedly made the strandflat somewhat smoother because the hollows in the till plain were filled in and the high places were eroded. The glacier which eroded bedrock and deposited the till could have been the one immediately east of Neny Fjord Thumb (unofficial name) when it was larger, a local fringing glacier located at the foot of Neny Fjord Thumb (unofficial name), a local glacier fed in part by the outflow of the Bowl Valley Glacier (unofficial name) around the Needle (unofficial name), or a combination and union of these glaciers (Holtedahl, 1935, p 17). The writer believes that the knobs were transported and deposited by ice. They are too large and

too fragile, because of their closely spaced joint system, to have been picked up from beneath a glacier and to have been transported sub-glacially or en-glacially. They probably fell from the cliffs of Neny Fjord Thumb (unofficial name), from the Needle (unofficial name), and from other felsitic cliffs onto a glacier which later dropped them on the strandflat. The fact that red granite is found in place at the northwest end of the strandflat, and that it is not abundantly found as erratics on the other parts of the strandflat, proves that the glacier did not come from this direction.

Following the erosion of bedrock by a glacier, the deposition of sub- and en-glacial till, the deposition of the knobs, and the deglaciation of the area, the strandflat was invaded by the waters of the fjord. Beach deposits were formed from the underlying till, bedrock, talus, and from the knobs and their talus aprons. Following the formation of the highest beaches, sea level dropped as much as 20 feet in relation to the land; and it was during this period that the marine cliff cut in till was formed and the bedrock cliff was exhumed.

A prominent strandflat occurs on the north side of Neny Island. It is several hundred yards long, as much as 150 yards wide, and it slopes gently seaward. It is cliffed on its seaward side and on its landward side there is, in places, a low bedrock cliff above which is talus. The surface of the strandflat is covered with elevated beach gravels which, along the seaside cliff, rest on bedrock. The beach gravels are in places deeply buried by talus and elsewhere are veneered with angular fragments which came from the talus slopes above and from a shattering of the beach gravels by frost (Fig. 40). The variation in the height of the bedrock surface on which the beach gravels rest indicates that it was probably cut by glacial rather than by marine action. The fact that no prominent strandflat is found on the west end of Neny Island, where the waves are strongest and where the other factors such as topography and resistance of bedrock are presumably similar, supports this view. Following deglaciation, the glacially cut platform was submerged and beach gravels were deposited on it as sea level dropped with respect to the land. Before the beach gravels were deposited, the platform may have been slightly smoothed by wave action. The seaside cliff is similar to that found at the strandflat near Neny Fjord Thumb (unofficial name), and it was therefore formed by glacial action. Chasms are found along the cliff which cut back into the strandflat. They may be due to wave action. To summarize, the strandflat owes its origin to glacial erosion which cut the bedrock platform and cliffs, to a minor amount of marine erosion which may have formed the chasms and smoothed the bedrock platform, to the deposition of beach gravels, and to an uplift of the land with respect to the sea. Smaller strandflats were found on the east and northwest sides of Neny Island.

Figure 40 - Talus Burying Elevated Beach Gravels on the North Side of Neny Island. Note Roundstones Immediately Above Bedrock and Below Talus.

WEATHERING

Weathering produces well-developed vertical leaf-like plates of gabbro and occasionally of pink granite in the bedrock on Neny Glacier Island (unofficial name). They were not seen elsewhere. The individual plates are usually between 1/8- and 1/2-inch thick, less than 10 in. long measured in the horizontal, and a few inches measured in the vertical (Fig. 41). In an area of several hundred square feet their orientation may be constant. Elsewhere it varies so that adjacent plates may be at right angles to each other. Individual areas of a few thousand square feet completely covered by these plates are present. In the break-up of bedrock into a residual gravel they are in these areas in intermediate stage. The plates are not significantly stained and the resulting gravel appears to be fresh and unweathered. It seems logical to suppose that these plates are the result of fracture cleavage or some other closely spaced foliation which has been opened up and widened by weathering processes. The diverse orientation of the plates may be due in part to frost action and other surficial processes. They may, on the other hand, be due to a type of weathering controlled by widely spaced joints, similar to that which produces the plates and shells on spheroidally weathered boulders, although this theory has its difficulties. The absence of staining suggests that they are probably due in part, at least, to frost action. Gabbro absorbs more insolation than the lighter colored rocks and therefore freezing and thawing should be more prevalent in areas of gabbro. This may explain the fact that the feature is almost wholly confined to gabbro.

The summit of the western end of Neny Glacier Island (unofficial name) is covered with a felsenmeer of hundreds of oddly shaped, weathered morainal boulders. They are round, subround, and smooth; shaped like lemons, dumbells, and concretions; and they vary in length from a few inches to 4 or 5 ft (Fig. 42). Many of the boulders are covered with pits as much as one in. deep. These pits are so abundant and so closely spaced on some of the boulders that a fretted surface has been developed. The smooth, round surfaces which characterize many of these boulders have apparently been formed by an enlargement and coalescing of the pits, and they are not stained with limonite (Fig. 43). It is not understood, however, why the smooth surfaces are not pitted or at least pocked with an occasional embryonic pit. A specimen was seen which had a hole weathered through it. The bottoms of these boulders are buried by morainal material and by the products of this weathering. They tend to be angular, are not as smooth, are stained with limonite, exfoliate in small slabs and plates, and are not pitted. These boulders weather differently, therefore, above and below ground level. Most of them are gabbro. The medium-grained gabbros have better pits and smoother weathered surfaces than the other gabbros.

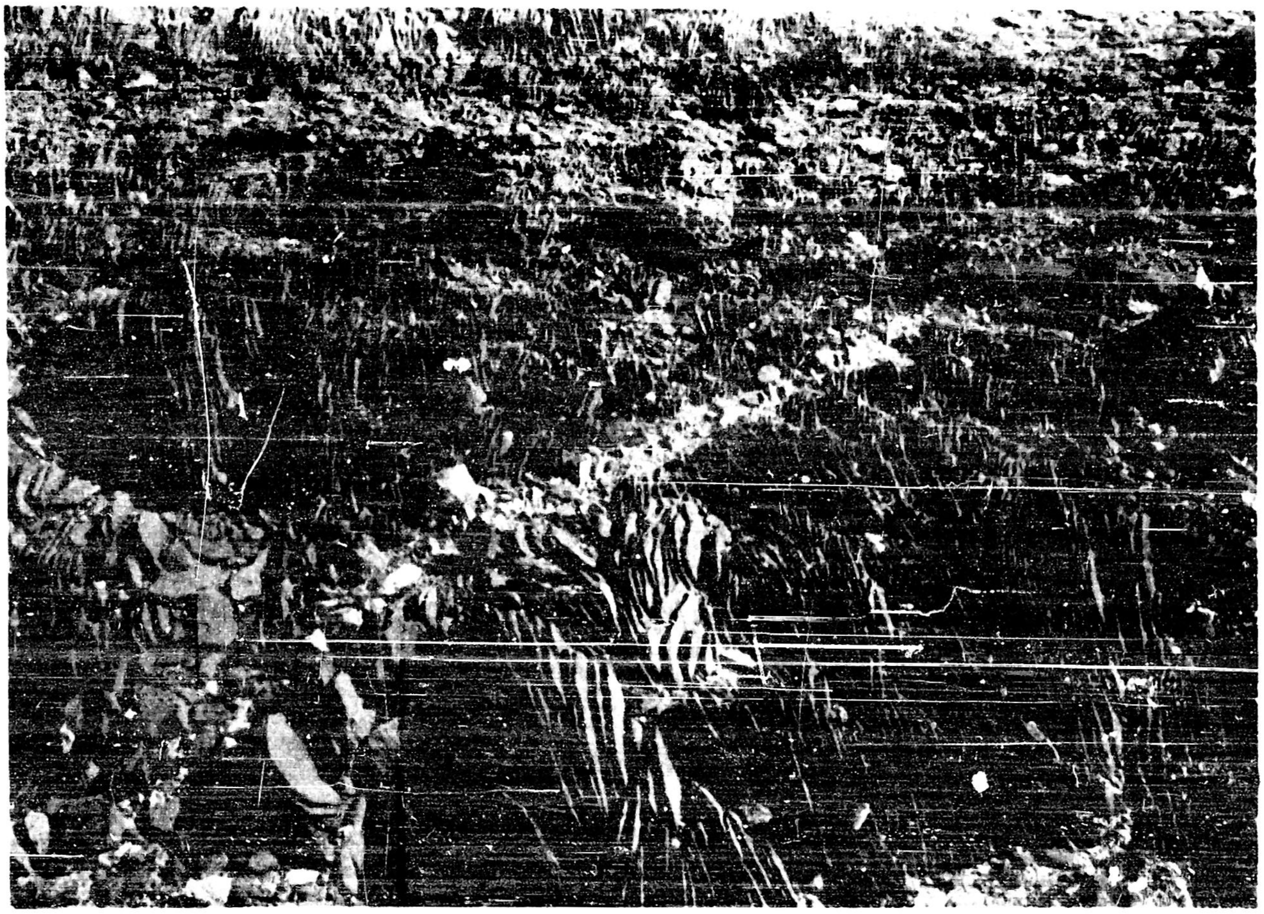


Figure 41 - Vertical Plates in Gabbro Formed by Weathering, Neny Glacier Island (Unofficial Name)

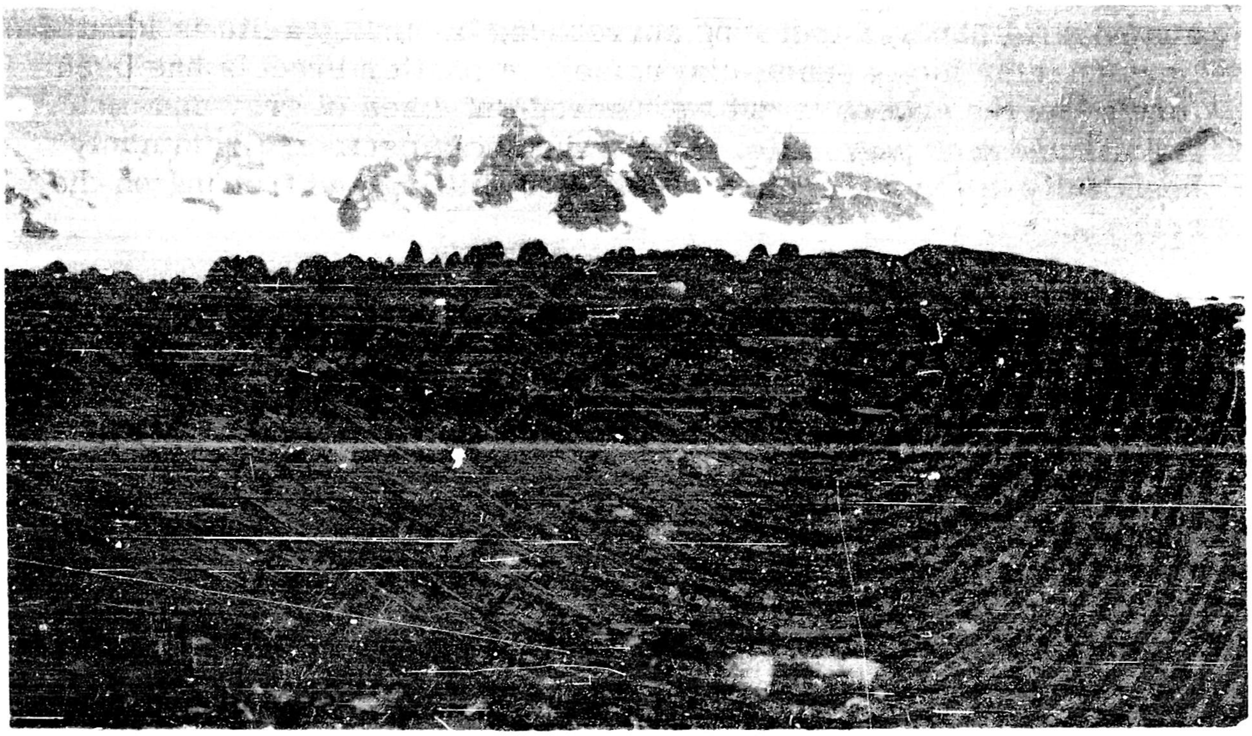


Figure 42 - A Felsenmeer of Oddly-Shaped, Weathered Morainal Blocks at Neny Glacier Island (Unofficial Name)

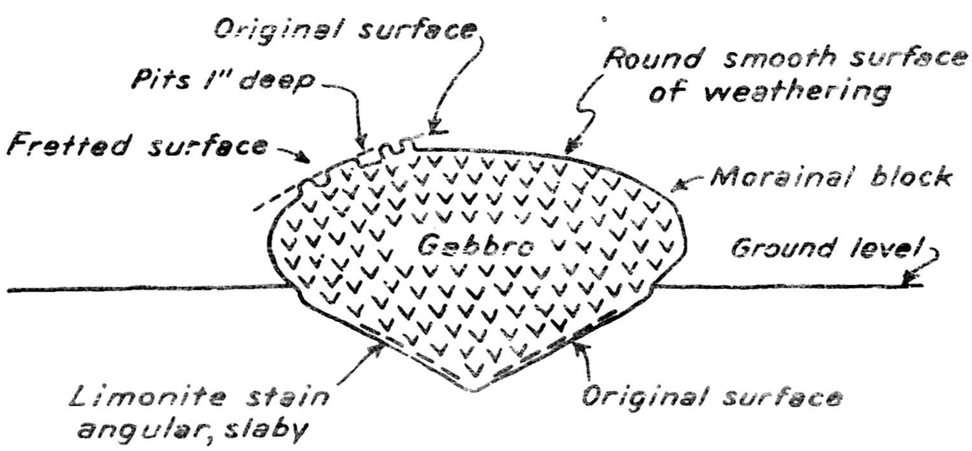


Figure 43 - Diagrammatic Sketch of a Weathered Block at Neny Glacier Island (Unofficial Name)

A dike-like roof pendant of gabbro usually between 20 and 30 ft wide and several hundred feet long surrounded by pink granite is located on Neny Glacier Island (unofficial name). A shatter breccia has been formed as the gabbro is cut by hundreds of dikes of gray and pink granite and pink pegmatite. The gabbro fragments are commonly beautifully pitted and fretted. Here, too, pitting and fretting on the acid rocks is very uncommon.

The basic rocks in this area weather more rapidly than the acid. This is shown by the gabbro inclusions which are commonly weathered below the surface of the granitic country rock and by the scarcity of pits in the acidic rocks. There was no evidence of sand blasting.

Bedrock, angular fragments, and roundstones, on the upper and older parts of the elevated beaches on Stonington Island, are commonly pitted at the surface (Fig. 44). The pits vary in width from a fraction of an inch up to 3 in. or so, and they may be more than one in. deep. A square foot of rock surface may have as many as 100 pits (Figs. 45, 46). They are so abundant that they give the rocks the appearance of being vesicular. The pitted rock is not too hard as the surface can be broken off by pressure with the fingers or hand. Elevated ridges which stand a fraction of an inch above adjacent areas are also present. These are undoubtedly due to zones in the rock which are more resistant to the weathering processes. The rocks are not stained by limonite or other minerals. These features are common on the basic rocks, very uncommon on the acid. Teichert (1939) has called attention to the fact that the hardness of ice increases with decreasing temperature and Blackwelder (1940) showed by laboratory tests that at -78.5°C the hardness of ice is approximately 6 on the Mohs scale. Naturally occurring ice with a hardness of 5 should not be too uncommon and it is, therefore, not surprising that features have been described which were thought to have resulted from the corrasive effects of wind-blown snow (Teichert, 1939). Pitted surfaces and potholes in the Rockefeller Mountains, Antarctica have been described by Wade (1945, p 73) which he believes are due to the corrasive effects of wind-blown ice crystals and rock fragments. The only proof which is given that they were formed by this process is the existence of the pitted surfaces and potholes themselves. It is certain, however, that the pits and ridges on Stonington Island are not the result of corrasion by wind-blown snow, dust, or sand because: (1) The smooth, polished, fluted, facetted surfaces with the cuspate hollows and interfacet edges which characterize ventifacts (Mather, Goldthwait, and Theismeyer, 1942, pp 1167-1170) are not found on these pitted rocks or on the other rocks in the area. (2) The pitted surfaces would be hard, not crumbly, if eolian action were important in their formation. (3) Significant quantities of wind-blown dust or sand were not seen either in the air, on the ground, or on the snow. (4) The

Figure 44 - Pitted Rocks of Basic Composition Formed by Weathering, Stonington Island

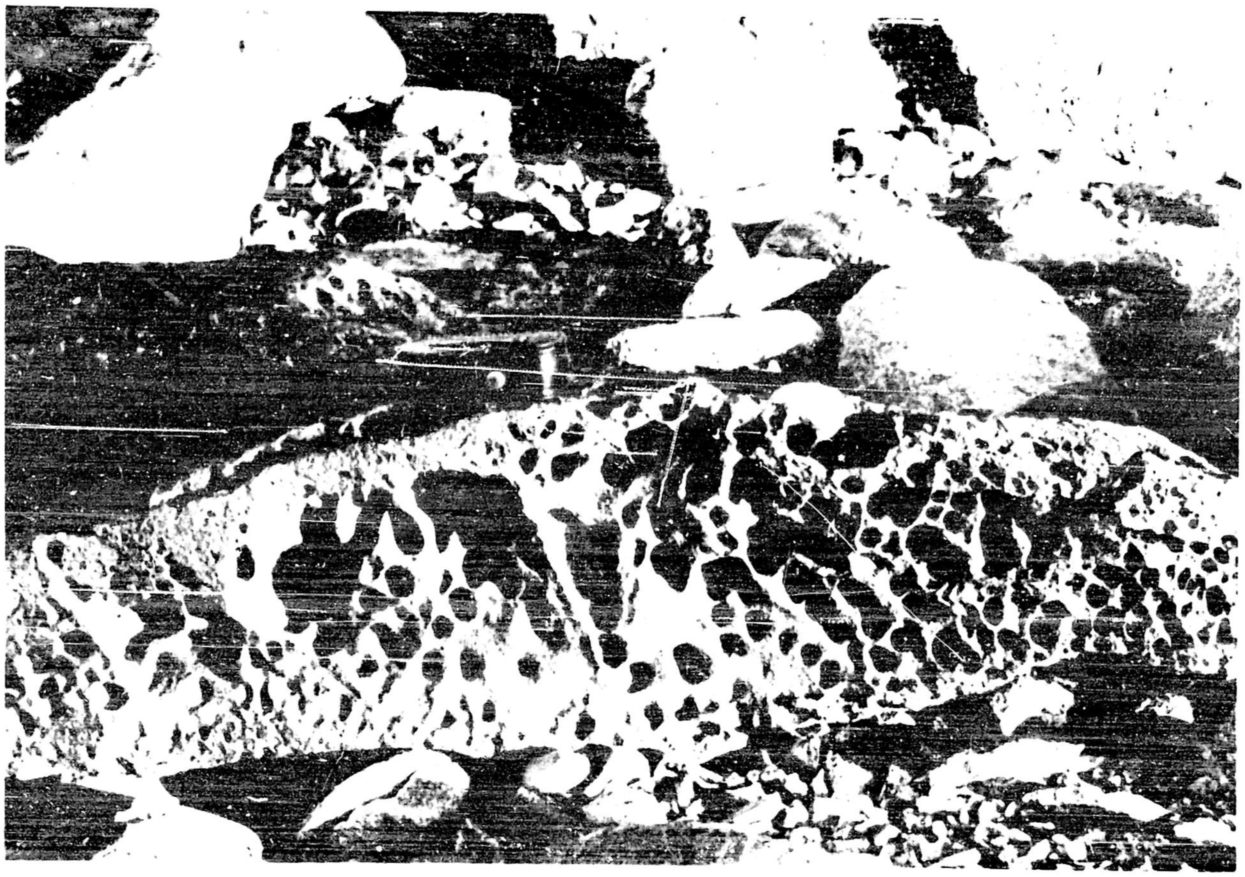


Figure 45 - A Fretted Surface Resulting From the Weathering of a Basic Fragment Found on Stonington Island

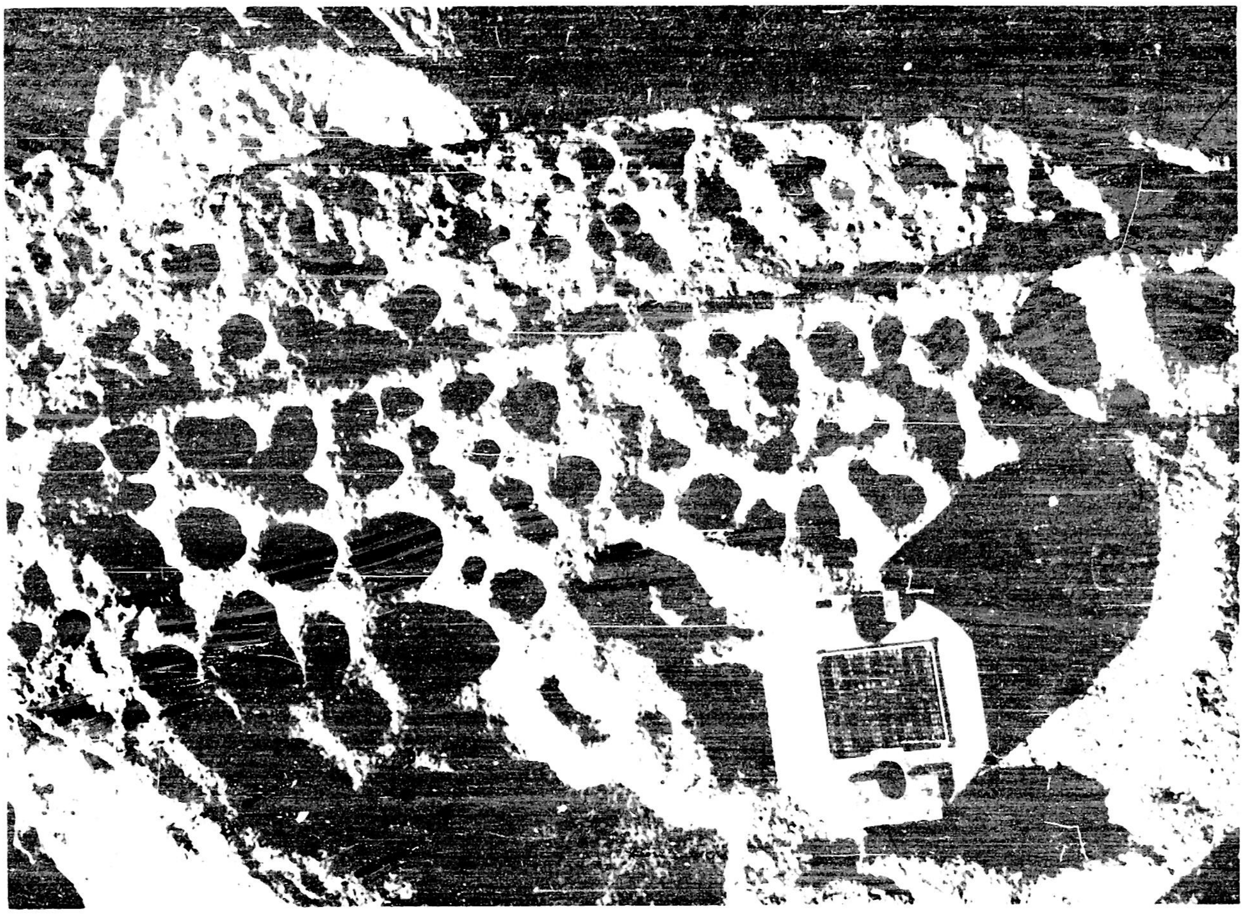


Figure 46 - Pits and Ridge Formed by Differential Weathering, Stonington Island

temperatures (Peterson, 1948a, p 7) are not low enough to give ice the hardness necessary for wind-blown snow to corrade igneous rocks. (5) The snow is so plentiful that the rocks are continuously and completely covered during the cold season. (6) The pits are probably too deep and narrow to have been produced by eolian action. Some of the flakes and grains, however, which are loosened from the rocks by the weathering processes are probably removed by the wind. The lack of staining suggests that mechanical weathering is important. The localization of the pits is not understood.

Pits weathered in the coarse pink granite on an unnamed island not far from Black Thumb Mountain are common. The largest are nearly one ft deep and somewhat wider. They have been formed by granular disintegration and the resulting gravel is also common. The process is accelerated along joint planes. In general, however, accumulations of granules, flakes, and slabs resulting from the disintegration of bedrock are not common in this part of the Antarctic due to the recentcy of deglaciation.

Diorite, trap, and other rocks crop out on one of the small islands of the Terra Firma group. In places the diorite is so badly weathered that there is a great deal of rotten rock and residual soil. The weathered diorite is commonly case hardened at the surface and is stained brown and yellow. A small cliff was seen which was cut in diorite containing gray inclusions. The diorite was weathered whereas the gray inclusions were hard and unweathered. The gray inclusions stood out in relief because the weathered diorite was falling off the cliff in small fragments. Terra Firma II Island is between this island and the largest island in the group. Here the country rock is also diorite but it is not as badly weathered as that on the other island. This difference in the degree of weathering between the diorites of the two islands is perhaps due to the fact that Terra Firma II Island, being closer to the icecap on the largest island of the group, may have been more recently deglaciated. It may, on the other hand, be due to differential mineralization of the two diorites.

Bedrock stained by limonite is common and is widely distributed in the Marguerite Bay area. Considerable areas on the northwest side of Neny Island are deeply stained with limonite, more than 50 percent of the rocks visible on Mushroom Island are covered with limonite, and similar areas are found in Bingham Col, Stonington Island, Terra Firma Islands, and elsewhere. In many cases they have probably resulted from the oxidation of pyrite.

ELEVATED BEACHES

More than 20 well-developed and easy-to-recognize elevated beaches are found in the Marguerite Bay area (Table I). This is perhaps surprising, as at some of these localities the sea is open for only 2, 3, or 4 months during the year, and in most places a barrier coastline is present.

Neny Glacier Island (unofficial name) is in the eastern part of Neny Fjord (Fig. 2). It is less than a mile long and the eastern end is attached to Neny Glacier. The island in the main consists of an eastern and western section tied together by an elevated beach. Elevated beaches are also found on the northwest, west, southwest, and south sides of the island (Fig. 47). The elevated beach between the eastern and western sections is a tombolo and at its highest point is approximately 50 ft above sea level. Not only were the western and eastern sections separated during the high stand of the sea, but the eastern section itself was also separated into four or more individual islands. A well-developed, extensive, elevated, ridged boulder beach which extends up to approximately 50 ft above sea level is located on the southwest part of the island.

Raised beaches are very common on the east and north sides of Neny Island. Those on the east side extend up to nearly 50 ft above sea level, cover extensive areas, and well-developed beach ridges are found on them. Elevated beach gravels are found as much as 90 ft above sea level on the north side of the island. In places they were deposited on a strandflat, are being progressively buried by talus and alluvial fan deposits, and rock fragments formed by the shattering of talus blocks and beach roundstones are found on them. Shallow pits several feet in diameter were seen on the beach ridges. They were probably formed by stranded growlers which melted away after being either buried or surrounded by beach gravel. A steep slope a few feet in height, similar to that diagramed by Joyce (1950, Figs. 1, 2), was observed on the beach face at one locality. It is not known whether it is due to: (1) The bedrock or ground moraine topography beneath the beach gravels. (2) Marine erosion or the erosion resulting from the break-up and removal of the icefoot. (3) Differential deposition of beach gravels.

There are many elevated beaches near the western end of Red Rock Ridge. The highest is on the north side at the entrance to a north-south chasm which cuts across the westernmost part of the ridge. This beach extends up to 110 ft (barometric reading) above sea level and is composed mainly of large boulders 1, 2, and 3 ft in diameter. It is just above a tarn which is about 50 ft long and a few feet deep. To the northwest and below

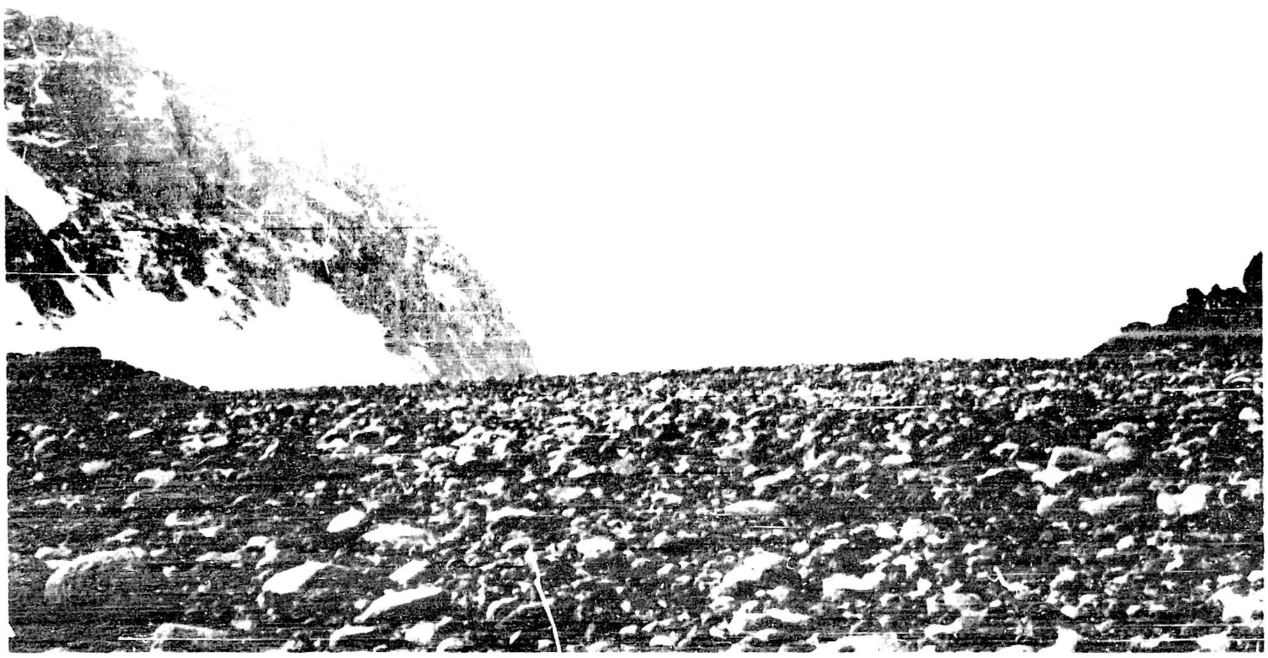


Figure 47 - Elevated Boulder Beach on Neny Glacier Island (Unofficial Name)

Figure 48 - Elevated Beach 27 Feet Above Sea Level on an Island Between Black Thumb Mt. and Refuge Islands. Bay Ice and Barrier in the Background.

the tarn, there is a series of beach ridges. Above the beach and perhaps burying some of it, there is a talus slope composed of huge fragments. The angular talus fragments stand out in sharp contrast to the round and subround beach boulders. It seems unlikely that the waves rolled or threw the roundstones found in the highest part of the beach much more than 10 ft above the sea level of that time. Approximately 100 ft of uplift of the land relative to the sea is therefore indicated for this area. The most prominent and extensive beach is located on the south side of Red Rock Ridge. It extends westward from the barrier, past a block terrace, almost to the penguin rookery. It is approximately 2000 ft long and in places somewhat more than 30 ft above sea level. Red granite, granodiorite (?), and gabbro are the most common rock types found on the beach, but volcanic breccias and porphyries alien to the immediate area are also present. Most of them were probably in the till from which the beach gravels were derived. Others may have been deposited on the beach by icebergs and sea ice.

An excellent elevated pocket boulder beach is located on an unnamed island between the Refuge Islands and Black Thumb Mountain. It is more than 200 ft long, is more than 600 ft wide and extends 27 ft above sea level. Beach ridges are found on it, and beach roundstones were found as much as 19 ft higher (Fig. 48). Pitted rock and heaps of granules due to weathering are found on the upper part of the beach. Gray granite, pink granite, pink felsite, black felsite, gneiss, trap, trap porphyry, aplite, and volcanic breccia roundstones are present on the beach. As the volcanic breccia is not indigenous to the island, it must have been brought to it by the nearby glacier or by either icebergs or sea ice. Other less extensive and lower elevated beaches are also present on the island. Three small islands tied together by tombolos are located a short distance from it. Beach gravels which are slightly elevated are present in a dike chasm on the largest of these. Clean rocks crop out on most of the island. The absence of a till veneer may be due to wave washing.

An elevated beach which covers many acres is found on the mainland at Black Thumb Mountain. The upper part is approximately 25 ft above sea level and several hundred feet from the present strandline, and it is being progressively buried by talus.

A large part of Stonington Island is covered with well-developed elevated cobble and boulder beaches. The highest part of the island is approximately 80 ft above sea level and beach gravels are found on it up to 70 ft. Only small, bare, bedrock knobs project above the beach gravels (Figs. 49, 50). During the highest stand of the sea the island was probably entirely submerged; at a later time several small bedrock islands were present; still later pocket beaches, tied islands, and

Figure 49 - Elevated Beach on Stonington Island

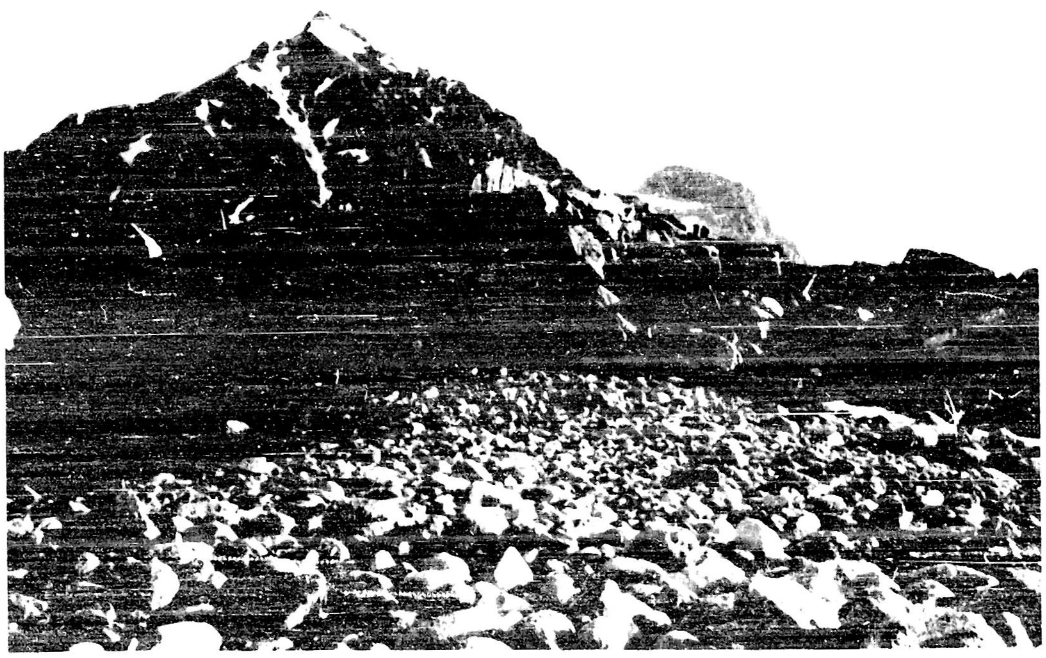


Figure 50 - Elevated Beach Ridge Scores of Feet Above Sea Level. Many Roundstones, Pitted and Roughened by Weathering, Stonington Island.

tombolos were formed, and continued emergence finally resulted in the present configuration of the island. Beach ridges occur, but they are not prominent. The upper, older parts of the beaches which are close to the bedrock knobs are veneered with chips and flakes spalled from the knobs. On the older parts of these beaches, many of the roundstones of basic composition are pitted. The pits are numerous, well-developed, and commonly more than an inch deep. The acidic coarse-grained roundstones on the older parts of the beaches are commonly roughened by exfoliation, and accumulations of spalled fragments often surround them (Nichols, 1947a). Roundstones split and shattered by frost action are also not uncommon on the older parts of the elevated beaches.

A cuspate clifflet or scar is present on the beach face near the eastern end of the island. It is concave toward the bay, extends up to about 10 ft above sea level, and the beach above the clifflet is undisturbed. Similar clifflets were not seen elsewhere. It is not a beach cusp as the clifflet is much too steep, and it is apparently not a wave-eroded beach cusp as the height of the clifflet does not vary appreciably. The ice-pushed ridges which are found on Arctic beaches are associated with scars from which the material to form the ridges was derived. They are formed by the thrusting of icebergs and sea ice into the beach deposits (Nichols, 1953). As a ridge is not associated with this clifflet, it appears as if it was not formed in this way. The absence of a ridge and the presence of a normal beach face above the clifflet indicate that beach gravel has been removed from the area. The icefoot which joins the land and sea ice between the high- and low-water marks becomes, on disintegration, a powerful transportation agent as beach material frozen to the under side is rafted away (Joyce, 1950, p 646). Perhaps this clifflet was formed in this way. Beach cusps formed before the clifflet may have been in part responsible for the cuspate shape. Its elevation proves it to be a youthful feature.

The important criteria used in identifying these elevated beaches were the presence of abundant roundstones above sea level, of topography which slopes down to sea level, and of beach ridges roughly parallel to the high tide mark. No whalebone, shells, or organic remains of any kind were seen in these beach deposits. This is probably due to the fact that these beaches are composed mainly of cobbles and boulders so that on the beach face organic material is quickly destroyed by attrition.

It is often difficult to decide whether a beach has been elevated, because it is not easy to determine how far above sea level gravel can be thrown by wave action on any particular beach. The height to which beach gravel can be thrown above sea level is dependent upon: (1) The strength of the waves (2) The size of the beach roundstones (3) The slope of the

beach face and adjacent terrain. In general, the steeper the slope, the higher beach material can be thrown because of the decreased length of the horizontal component of the trajectory. The roundstones on some of the beaches contain dark minerals. On these beaches a limonite stain was formed on the roundstones above the zone of wave action. The limonite line above which the roundstones were stained and below which they were not stained was used to separate the active part of the beach from the elevated inactive part. Its existence demonstrated the presence of an elevated beach and its position indicated the height to which the waves were acting; and it aided in estimating the amount of the uplift of the land relative to the sea which was necessary to account for the altitude of the raised beaches.

Most of these elevated beaches when formed were ocean-side beaches, some were pocket beaches, a few were tombolos. The major features of the topography of these beaches are not due to the deposition of the beach gravels, but to the slope of the bedrock and ground moraine on which they rest.

Ground moraine is the most important source for these beaches. Talus is a much less important source. The insignificant amount of post-glacial marine crystalline bedrock erosion which has occurred indicates that here as elsewhere this does not produce a significant supply of beach material.

Although beach ridges are found on these elevated Antarctic beaches (Table I), prominent ridges such as those on Victoria Island N.W.T. (Washburn, 1947,pl 14) are not present. The absence of prominent beach ridges is perhaps due to: (1) Most of the beaches are composed mainly of large cobbles and boulders. Their weight made it difficult for the waves to pile them into prominent ridges. (2) The strength of the waves and the supply of material may have been more or less uniform. (3) The rate of uplift may have been constant. (4) Beneath a thin surficial veneer, the beach gravels were permanently frozen.

Pits and ice-pushed ridges and scars are not common on these elevated beaches. This is perhaps surprising in a region where icebergs, bergy-bits, growlers, and sea ice are so prevalent (Washburn, 1947, p 80). Their absence is probably due to: (1) The presence of an icefoot which veneered and protected the beach gravels (Joyce, 1950, pp 346-349). (2) The coarseness of the beach gravels and their frozen condition during most of the year. (3) Destruction of these features by wave action during the short summer months when the sea ice was absent and by wave action beneath the sea ice during the rest of the year. (4) The off-shore profile prevented icebergs and bergy-bits from grounding on the beach face. (5) The thickness and stability of the sea

TABLE I

ELEVATED BEACHES OF MARGUERITE BAY, PALMER PENINSULA

Location	Maximum altitude	Area - Dimensions	Special features	Remarks
Mushroom Island	approximately 20 ft.	small		Being buried by talus.
Moraine Point (unofficial name)	approximately 20 ft.	small		Beach roundstones intermingled with morainal fragments.
Black Thumb Mountain	25 ft.	many acres		Upper part several hundred feet from strandline. Upper part being buried by talus.
Small unnamed island between Black Thumb Mountain and Red Rock Ridge. Bearing to center Bingham Col N 25°E Bearing to Black Thumb Mt. N 127°E	12 ft.			Elevated?
Small unnamed island near Black Thumb Mountain	above sea level	small; in a chasm		Elevated?
Small unnamed island between Black Thumb Mountain and Red Rock Ridge	27 ft.	200 ft. long 600 ft. wide	Pocket beach.	Beach ridges. Beach roundstones up to 46 ft. Other slightly elevated beaches.
Red Rock Ridge (north side)	110 ft.		Coarse boulder beach.	Highest beach in the Marguerite Bay area.
Red Rock Ridge (south side)	somewhat more than 30 ft.	2000 ft. long		
Neny Island (east side)	nearly 50 ft.	extensive	Well-developed beach ridges.	
Neny Island (north side)	90 ft.	extensive	On strandflat in places.	Buried by talus and alluvial fan deposits in places; pitted beach ridges.
Roman Four Mountain	slightly elevated			At least three small beaches.
Bingham Col (east corner)	approximately 30 ft.			
Neny Fjord Thumb (unofficial name)	more than 20 ft.	extensive	On strandflat.	
Neny Glacier Island (unofficial name)	approximately 50 ft.	extensive	At northwest side, beach cliffed at strandline.	In part elevated tombolos. Many areas.
Islands 50 miles west of Stonington Island	above sea level			Two small beaches - elevated?
Two islands 10-15 miles southwest of Adelaide Island	above sea level			Two small beaches - elevated?
Stonington Island	70 ft.	Cover large part of island.	Crescentic scars. Pitted roundstones.	

ice prevented ocean currents and wind from pushing it up onto that part of the beach which is above the action of the waves.

No elevated off-shore marine deposit was found although Andersson (1906, pp 58-59) has reported from northern Graham Land such an occurrence, and they are, of course, very common in other parts of the world (Goldring, 1922, map 2). Many of the beaches are wide and high enough so that this material may have been deposited where beach gravels are now found some time after deglaciation and prior to the deposition of the gravels. If so, it was apparently destroyed by wave action or buried by beach gravel while being elevated up through the breaker zone. Its absence suggests that no rapid uplift of any significant magnitude occurred during the period of emergence.

Well-rounded beach gravel is continuous from the marine limit down to the present strandline. This proves that the uplift was at no time so rapid that significant quantities of beach gravel were not formed in the breaker zone. There is, moreover, nothing in the distribution or characteristics of the beach gravel to indicate that the uplift was not continuous, uniform, and slow.

These elevated beaches are being buried in places by talus (Fig. 40), alluvium, and by fringing glaciers and snowdrift ice slabs.

Before elevated beaches can form, there must be: (1) A deglaciated area, the topography of which is such that beaches can form on it. (2) A source material for the beach deposits. The height of any particular elevated beach is dependent on the above, on the height to which the waves can throw beach material above sea level, and on the following: (1) The former thickness of the ice at the beach locality, as this controls the amount and rate of crustal recoil. (2) The distance of the beach from the edge of the ice, as this is related to the length of time the area has been deglaciated. It cannot be predicted where the highest beach will be found, but areas distant from the present ice terminus are favored. The northern part of Alexander I Island is the best place in the Marguerite Bay area south of 68°30'S to find a beach higher than the 110-ft beach on Red Rock Ridge. Millerand Island should also be investigated. The area north of 68°30'S is more favored, however, as ice-free coastal areas are probably more common. The highest beach might be found on a strandflat connected with a high island, promontory, or fjord wall.

The elevated beaches in Graham Land have been described by Andersson (1906, pp 57-59), Nordenskjöld (1913, p 14), Bongrain (1914, p 49), and Fleming (1940, pp 94, 97). The highest is 80 ft above sea level (Table II). The elevated beaches in South Victoria Land have been

TABLE II

ANTARCTIC ELEVATED BEACHES, MARINE CAVES, MARINE TERRACES

Location	Altitude	Remarks	Observer or Authority
Cockburn Island, Graham Land	13 ft.	Beds of sand and gravel.	Andersson, 1906, pp 57-58
Hope Bay, Graham Land	10 ft. above sea level, perhaps higher	Numerous rounded pebbles not now reached by waves.	Andersson, 1906, pp 57
Sidney Herbert Sound, Graham Land	about 13 ft.	Marine stratified bouldery fossiliferous clay. Marine till. Deposited below sea level.	Andersson, 1906, pp 58-59
West Antarctica	32-49 ft.		Nordenskjöld, 1913, pp 14
Jenny Island, Marguerite Bay, Graham Land	26 ft.	Elevated beach, 1300-1600 feet long; 160-330 feet wide. Whalebone.	Bongrain, 1914, pp 49
South of Adelaide Island, Graham Land	80 ft.	Many beaches.	Fleming, 1940, pp 94, 97
Cape Barne, Ross Island South Victoria Land	180 ft.	Sponge spicules, serpulae, molluscan shells. Probably not a beach.	David & Priestley, 1909, pp 317-318
Cape Bernacchi, South Victoria Land	100 ft.	Terraces suggestive of raised beaches.	David & Priestley, 1909, pp 318
Terrace Island (20 miles N of Cape Bernacchi), South Victoria Land	80-85 ft.	Terraces. Sand and coarse gravel.	David & Priestley, 1909, pp 318
Backdoor Bay, McMurdo Sound, Ross Island, South Victoria Land	160 ft.	Diatoms, serpulae tubes, roundstones. Small area. Probably not a beach.	Priestley & David, 1912, pp 808-809
Cape Geology, Granite Harbor, South Victoria Land	about 50 ft.	One elevated beach.	Taylor, 1922, pp 22, 23
4 miles E of Cape Geology, Granite Harbor, South Victoria Land	about 50 ft. (top of cave)	Marine cave.	Taylor, 1922, pp 35-36
Inexpressible Island, Evans Coves, Terra Nova Bay, South Victoria Land	about 80 ft.	Raised boulder beach. Elevated seaweed.	Priestley, 1923, pp 53-56
Taylor Valley (Dry Valley), New Harbor, McMurdo Sound, South Victoria Land	at least 50 ft.	Numerous shells. Pecten Colbecki, Anatina elliptica, Limatula. Shallow water deposit.	Priestley, 1923, pp 56-57

escribed by Taylor (1922, pp 22-23, 35-36) and Priestley (1923, pp 53-7). The highest is approximately 80 ft above sea level. Sponge spicules, ol luscan shells, and serpulae have been reported on Ross Island at 180 above sea level (David and Priestley, 1909, pp 316-319; 1914, pp 266-76; Priestley and David, 1912, pp 808-810). These may be associated ith raised beaches but probably with marine deposits scraped from the cean bottom by glacial ice and deposited there. There is, therefore, ood evidence that the margin of a large sector of the Antarctic Conti-ent has recently been uplifted. It is generally agreed that this uplift is e to deglaciation (Priestley, 1923, p 57; Washburn, 1947, pp 55-56; aly, 1934, pp 112-148). If the margin of the continent has been recently evated 100 ft, and the above data indicate that it has (Table II); and if is assumed that the emergence is the result of isostatic adjustment to glaciation; and if, further, the specific gravity of ice is taken as 0.92 d that of the plastic subcrustal material whose movement in toward e deglaciated area caused the uplift as 5.00 (Daly, 1934, p 138); then lculation shows that the removal of approximately 540 ft of ice was sponsible for this uplift. This is undoubtedly a minimum figure for e thickness of the ice which has been removed during deglaciation cause: (1) In Fennoscandia and the other regions where deglaciation s taken place, equilibrium of the crust was not achieved until long er the ice had disappeared (Daly, 1934, p 65-69). It is unlikely that uilibrium has been reached where these raised beaches are found as ey are not far distant from the ice and deglaciation is still in progress. More deglaciation probably took place before the beaches were med than since. This is particularly true of the raised beaches on ny Glacier Island (unofficial name) and on Stonington Island as the ice s retreated only a short distance from these areas, and yet it was usands of feet thick here and its terminal position was many miles the west when it was full-bodied. These beaches can only record, refore, a fraction of the crustal recoil resulting from deglaciation. Still higher elevated beaches may be found as field work continues. study of the raised beaches of the Antarctic strongly suggests that on average a thickness of at least 1000 ft of glacial ice, and probably ch more, has been removed from the margin of the continent during laciation.

ASMS

A chasm several feet deep and a score or more feet in length was nd 100 ft north of the summit at the eastern end of Stonington Island. s high above sea level, elevated beach gravels are present at the om of the chasm, and what are presumably wave-smoothed surfaces found close by. The chasm has been cut in three parallel black dikes ch intrude a coarse-grained igneous rock to include the screens of

this rock which separate the dikes. The dikes have, therefore, located the chasm. It seems likely that glacial erosion initially formed the chasm and that it was later somewhat modified by wave action.

Red Rock Ridge is almost everywhere more than 1500 ft high. At the extreme western tip of the main part of the ridge there is a much lower ridge several hundred yards long and a few hundred feet high. This lower ridge is cut by chasms which cross it roughly at right angles. The largest of these chasms is scores of feet deep, it is above the marine limit, and therefore owes its origin to glacial erosion. It was not determined whether the chasm was located by basic dikes, many of which are oriented in the same direction as the chasm, or by other geologic structures.

A large chasm which is scores of feet wide and deep is located at the northwest end of the main Terra Firma Island (Fig. 51). A thick, presumably stagnant slab of ice terminating at sea level fills the bottom of the chasm. The country rock to the west and northwest of the chasm is diorite cut by basic pegmatite and granite dikes; and that to the east is felsite cut by epidote veins and basic dikes of various kinds. A gray dike which apparently located the chasm is found between the diorite and the felsite. As most of the chasm is above the marine limit and as there is no evidence of marine action in the lower part of it, this chasm also owes its origin to glacial erosion.

On the north side of Neny Island, small chasms are now being cut back into the strandflat by marine action. A small chasm 4 ft wide and somewhat deeper has been cut along a basaltic dike on the northwest side of Neny Island. It is at sea level and wave-worn surfaces are found in it (Fig. 52).

NEEDLES

A sharp-pointed, prominent needle a few hundred feet high, composed of closely jointed felsite is located close to Neny Fjord Thumb (unofficial name) (Fig. 53). This area was completely buried by actively moving ice during the Red Rock Ridge glacial stage. It seems most unlikely that the needle could have persisted or could have been formed under active ice. The jointed nature of the felsite, the huge talus banks which surround it (Fig. 36), as well as its slenderized shape prove that it was formed after the area was deglaciated. However, some slenderizing and over-steepening by glacial erosion may have taken place when it was a nunatak. Other less spectacular needles are also found in the area.

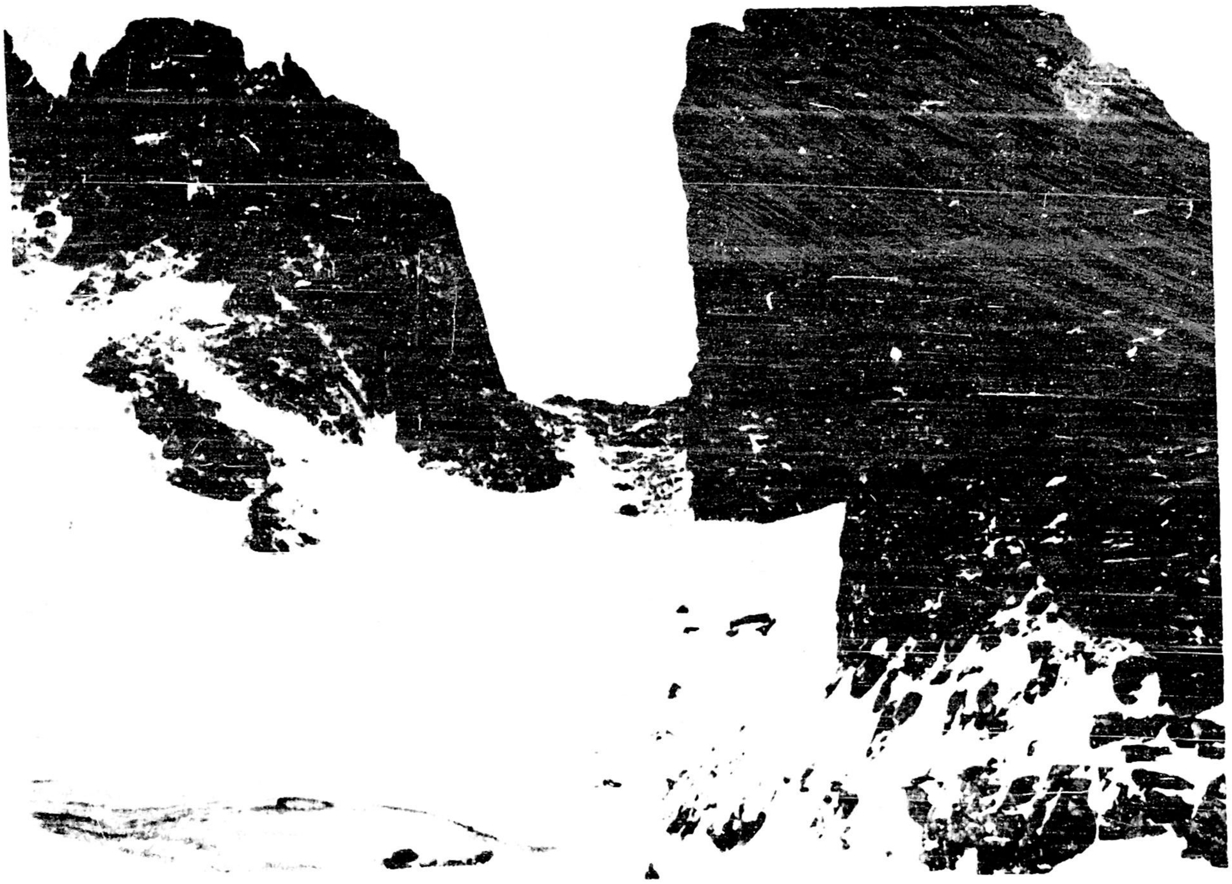


Figure 51 - Glacially Formed Chasm Located Along a Dike on the Largest Terra Firma Island

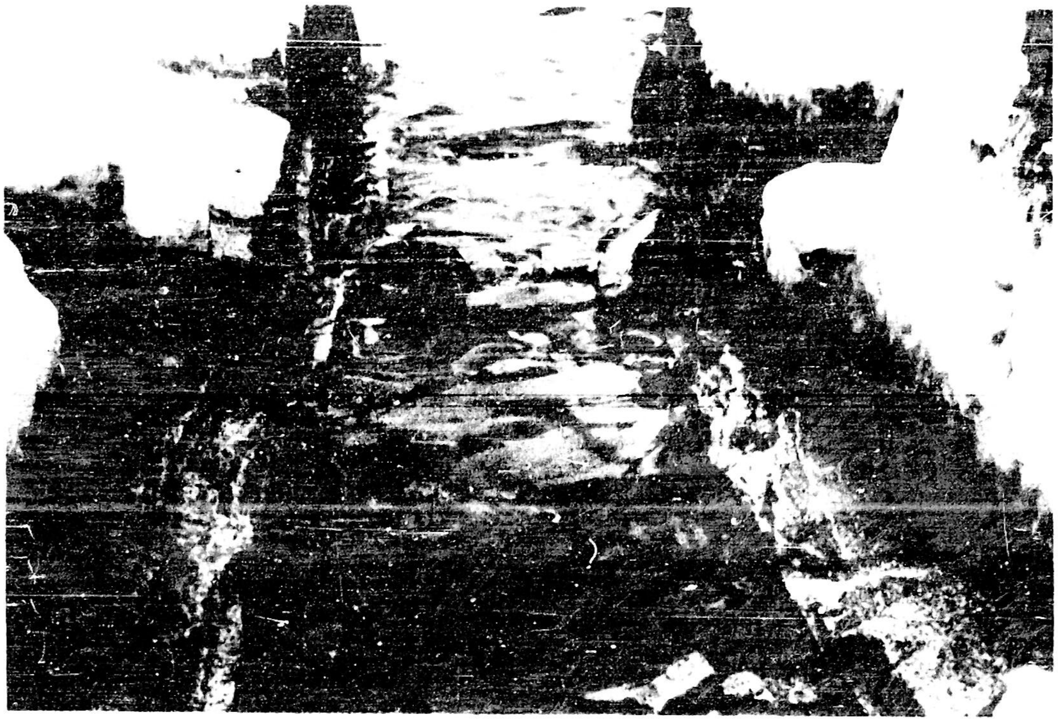


Figure 52 - Chasm Located Along a Basaltic Dike
on Northwest Side of Neny Island

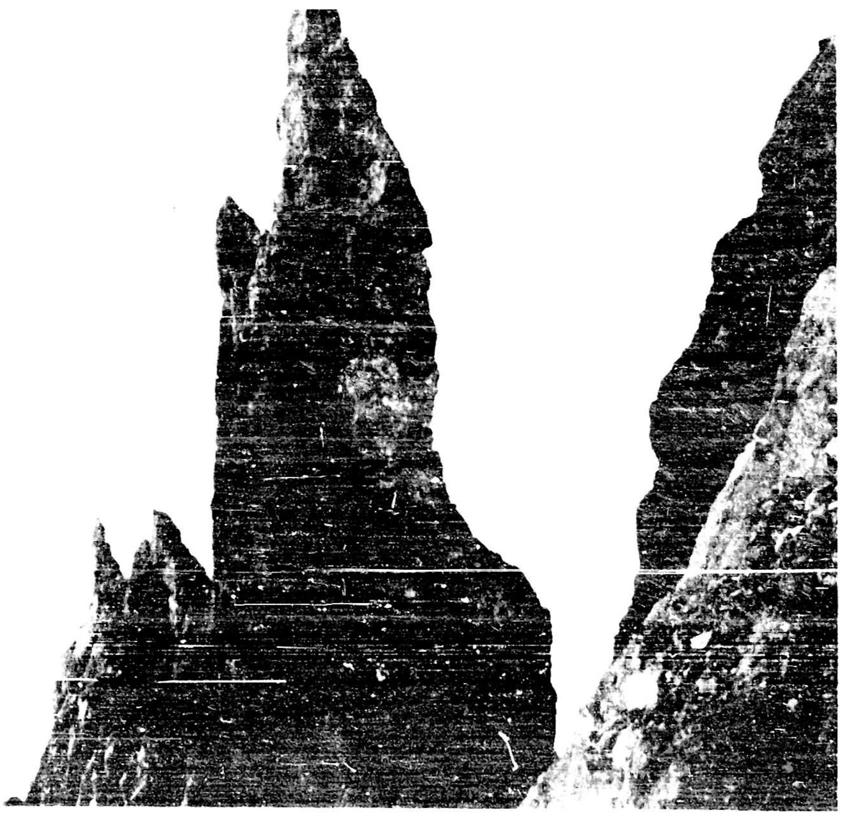


Figure 53 - The Needle (Unofficial Name) Near
Neny Fjord Thumb (Unofficial Name)

MARINE CLIFFS

Marine cliffs cut in either mantle or bedrock are not common. A small marine cliff is being cut at the present time in the beach gravels at the northwest side of Neny Glacier Island (unofficial name), and beach gravels are also being eroded on the north side of Neny Island. A larger marine cliff which was described above has been cut in till at the strandflat at the foot of Neny Fjord Thumb (unofficial name) (Fig. 36). As indicated above, small marine cliffs have been cut in the talus at the strandline on the north side of Neny Island. Small chasms cut in bedrock found in the strandflat on the north side of Neny Island and formed by glacial and/or marine processes are now being enlarged by wave action. These features are not found everywhere at the strandline, and it appears as if those described are due to local and not to regional factors.

TALUS

Huge talus slopes are found on Neny Island, at the foot of Roman Four Mountain, at Black Thumb Mountain, at Neny Fjord Thumb (unofficial name), and elsewhere. Talus cones and aprons hundreds of feet high are present on the east and north sides of Neny Island (Fig. 54). Shallow scars or depressions are found on the leeward side of some of the cones where the snow accumulates in greater quantity and where it forms a more permanent ground cover. It is not known whether nivation is a factor in their formation. There is some evidence that the scars may be due to a deficiency of deposition on the cones at these places because of the formation of pro-talus ramparts by the sliding downward of talus fragments on the snow slopes. Small, steep marine cliffs have been cut in the talus in places where it reaches the strandline. The steep cliffs perhaps maintain themselves because of the presence of ground ice in the talus. Talus is in places progressively burying the elevated beaches on Neny Island, Mushroom Island, and Neny Fjord Thumb (unofficial name). At several places on the north side of Neny Island talus cones are oblique to the cliffs at the foot of which they are found. This is due to the oblique alignment of the couloirs from which the talus was derived.

Talus containing large blocks as well as fine material is found on the east side of Neny Island. Small patches of alluvium have been deposited on this talus in the depressions on the up-slope side of some of these blocks. In this way alluvial flats were formed which have a surface area of a few square yards. The slope of the surface of the alluvium is much flatter than that of the talus (Fig. 55). When the depressions are completely filled, alluvium is swept around the blocks and the coarser material is deposited as a thin veneer on the steep talus immediately

Figure 54 - Talus Cones and Aprons on Neny Island

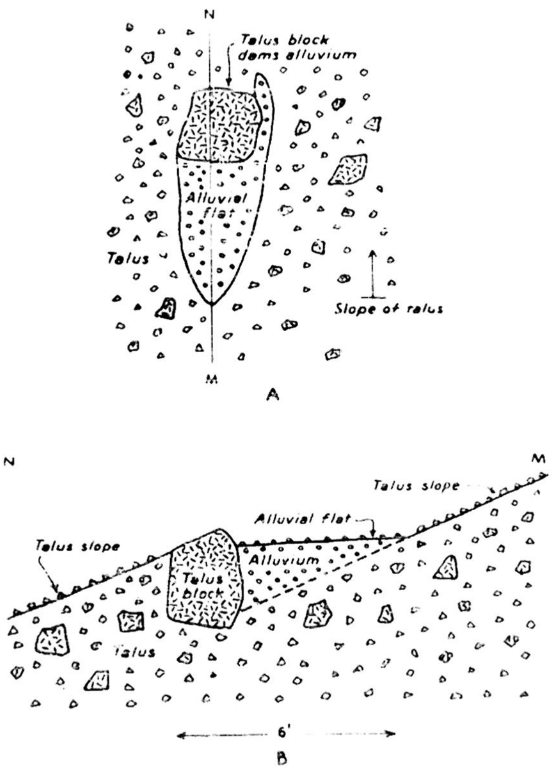


Figure 55 - Diagrammatic Sketches of Alluvium Deposited in Back of Large Block on Talus Slope, Neny Island

down-slope from the blocks. The alluvial fragments were not significantly rounded, as they have been transported only a short distance. The water which transported the alluvium probably came from melting snow and ground ice. The presence of ground ice is probably necessary for the formation of the alluvium as otherwise the water would sink into the talus and runoff would not take place. It was probably deposited after the snow cover on the talus was melted and before the ground ice had been melted to more than a few inches below the surface.

Heavy rainfall, fine-grained clayey talus, and the presence of vegetation would favor the formation of alluvium on talus slopes. However, when lithified alluvium is found interbedded in talus breccia, the possibility of the alluvium having been formed because of the former existence of ground ice near the surface of the talus should be considered.

Sand flows are common on the talus slopes in the sand pits of New England. A central channel margined by levees is usually found in their upper courses and bulbous units deposited one on the other are common in their terminal areas. Sand flows and mud flows should also be formed on larger talus slopes which are composed in part, at least, of fine-grained material. Lithified alluvium and lithified mud flow deposits can therefore be expected in talus breccia.

Talus which contained a great deal of fine material was found on Roman Four Promontory. The granule and pebble sizes in the talus were also slightly rounded. The talus-forming processes in this region, in general, do not produce roundstones and do not form fines abundantly. The rounded and the fine material was probably derived from glacial drift deposited above the talus when the ice was thicker. If this is correct, the upper glacial limit is higher than the areas where the fine-grained and rounded material was found. A small alluvial fan composed of fine-grained material was found below the talus. The formation of the fan was probably due in part to a couloir located above the talus which funneled and concentrated the melt water formed on the mountain. The melt water washed out fine material from the talus and deposited it, forming the fan below.

Channels, levees, and irregular depositional topography are found on one of the talus cones on Neny Island. These features cover several acres and they are large enough so that they can be seen for thousands of feet (Fig. 56). They are not the result of talus-forming processes. It is not known whether they were formed by mud flows or by running water (Bretz, 1935, Figs. 324, 332). In either case, melt water was necessary for their formation and the presence of ground ice in the talus would facilitate their development.

Figure 56 - Channels and Levees on Talus Cone, Neny Island

BLOCK TERRACES

Block fields are formed in many ways. Blocky talus slopes are examples of high-angle block fields. Block fields are found on fragmented pahoehoe, on aa, and on acidic lava flows (Nichols, 1938, pp 501-503; Finch, 1933, pp 769-770). They are also formed around volcanoes by the ejection of large, angular fragments. Mud flows and landslides may form extensive block fields (Blackwelder, 1928, p 471, [illegible]; McConnell and Brock, 1904, pl. 6) and they are found in the upper parts of alluvial cones and fans. The erosion of drumlins by waves and shore currents forms by the removal of the finer material the so-called boulder pavements which are common along the New England and Nova Scotia coasts (Nichols, 1948b, pp 97-98). Because the fragments are mainly angular rather than rounded, these pavements are more properly called block pavements. Morainal deposits are commonly blocky and the removal of the fines by running water may make them even more blocky. The formation of blocks by frost weathering and their movement away from the parent ledges by solifluction also forms them (Smith, 1949, pp 1500-1501). Residual block fields are also formed by frost action and by other processes.

Block terraces which are below the snow line are found close to sea level on the north side of Neny Island, on the southwest and northwest sides of Roman Four Promontory, and on the north, west, and south sides of Red Rock Ridge. One of those on Neny Island is shown in Figures 57 and 58. The terrace flat is approximately 300 ft long, 150 ft wide, and the upper edge is in places as much as 120 ft above the lower boundary (Fig. 59). The flat has a 6° slope, it is covered with large angular blocks, the margins are slightly higher than the central portion, and a small talus cone has been built on it. The blocks are not arranged in any pattern, water was neither seen nor heard running beneath them, and no direct evidence was found indicating the presence of snow or ice beneath them. The lower terrace slope has a 37° gradient and its lower and upper edges decrease in altitude from the inner to the outer side of the terrace. Between the lower edge of the terrace and sea level, which is only a few feet below it, bedrock crops out. A talus slope with the normal 30° inclination is found in a deep ravine above the block terrace. The ravine owes its existence in part, at least, to the presence of closely jointed trap dikes.

Three block terraces, all located below sizable ravines, are found on the northwest side of Roman Four Mountain close to the valley glacier (Fig. 60). They slope in the same direction as the valley glacier — that is, away from the glacier. The surfaces of these block terraces, however, do not line up with the projected profile of the valley glacier. There are also two block terraces on the southwest side of Roman Four

Figure 57 - Front View of Block Terrace at Northwestern End of Neny Island

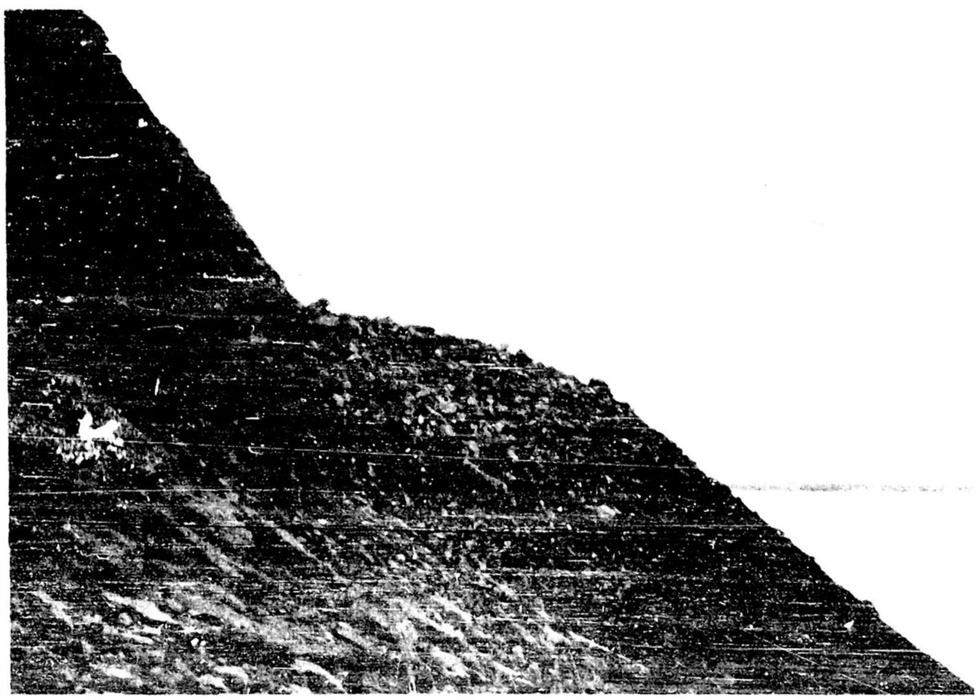


Figure 58 - Side View of Small Block Terrace at Northwestern End of Neny Island

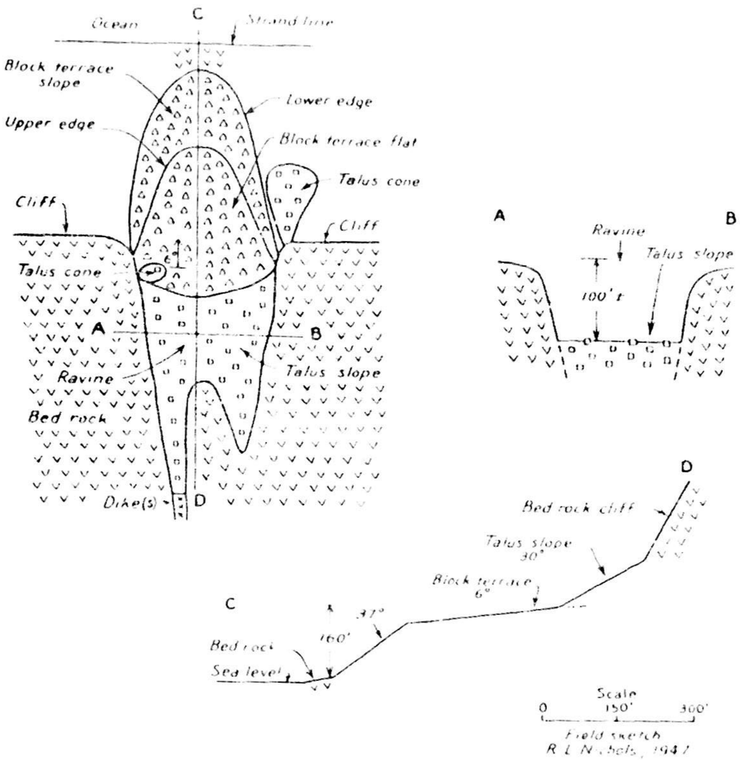


Figure 59 - Field Sketches of Block Terrace Shown in Figure 58

Figure 60 - Block Terrace (Right), Talus Cone (Center), Lateral Moraine (Left), and Cliffs of Roman Four Mt.

Mountain (Fig. 61). A fringing glacier which is in places moraine-covered is located immediately eastward. The lower terrace slope of one of these block terraces was found to have a gradient of about 37°. The knickpoint formed at the boundary of the terrace flat and the lower terrace slope is sharp; this is also a characteristic of the other block terraces.

A block terrace is found on the southwest side of Red Rock Ridge near its terminus, two or more coalescing block terraces are found at the west end of the ridge, and more than six are present along the fjord between Bingham Col and the west end of the ridge. Talus is found above the block terrace on the southwest side of the ridge and an elevated beach is found below it (Fig. 62). The average elevation of the terrace above the beach is approximately 100 ft, and it is somewhat higher than an adjacent moraine-covered fringing glacier. The lower slope has an inclination of 42°, and the lower slope of one of the block terraces on the west end of the ridge has an inclination of between 33° and 38°.

Water running between or beneath blocks was neither seen nor heard, no melt water issued from the terraces, and interstitial ice was not seen beneath the blocks. Nevertheless, the writer feels that an internal core of ice must be present. The facts which indicate this are: (1) The terminal slopes of the block terraces are as steep as 42° whereas the normal talus slope of the area where measured was only 30°. This suggests an ice matrix between blocks which holds them together and therefore enables them to stand at high angles. (2) There is a complete gradation from moraine-free fringing glaciers through moraine-veneered fringing glaciers to block terraces. (3) The block terraces are usually adjacent or close to fringing or valley glaciers. (4) The block terraces and the fringing glaciers have approximately the same relation to the mountain cliffs, about the same thickness and surface gradient, and they both slope away from the mountain cliffs. No data were obtained on the thickness of the layer of blocks.

The fact that they are not now moving is indicated by the following: (1) All of them terminate on land and there are no end moraines in front of them. (2) The regular shape of a talus cone on one of them and the presence of talus at the upper edge of some of them (Fig. 59). (3) They are on the average less than 100 ft thick and they rest on rather flat slopes (Matthes, 1900, p 190).

The absence of end moraines also indicates that the terraces have been stagnant since reaching their present boundaries. The volume of the talus which buries the terraces is in part a function of the length of time since they have been stagnant. It appears to be only a fraction of the total time during which talus has been forming in the area.

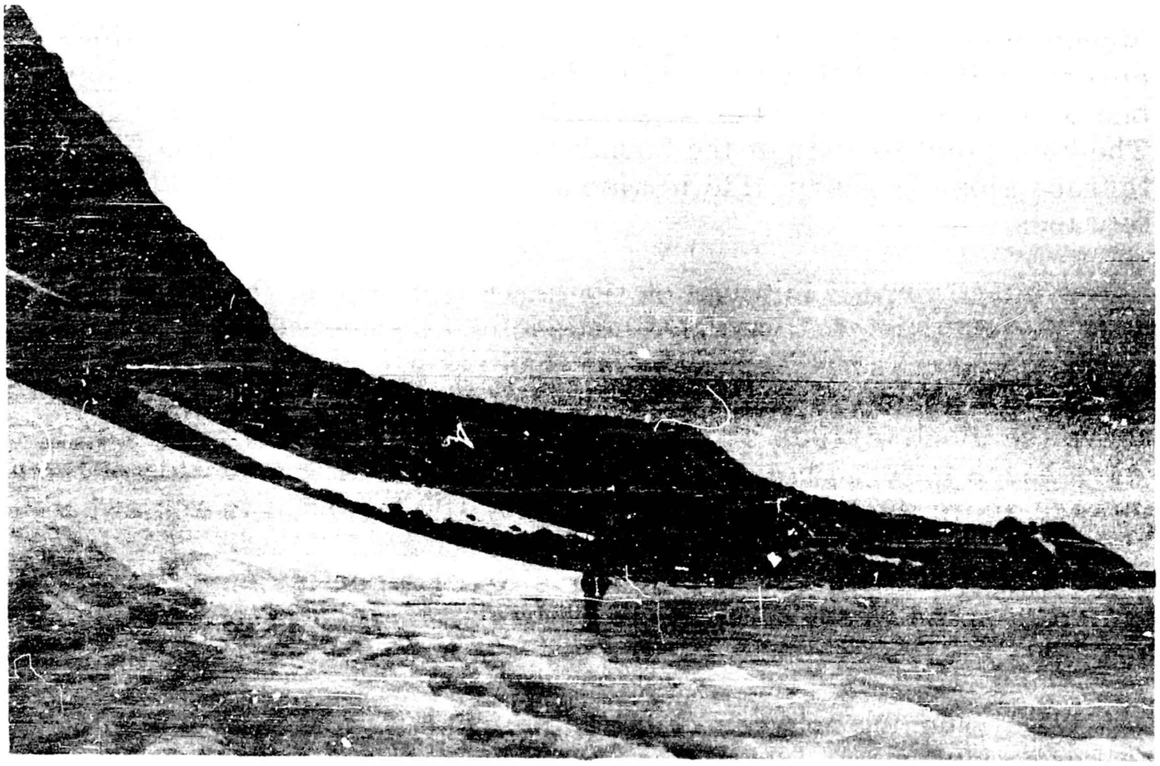


Figure 61 - Two Block Terraces on Southwest Side of Roman Four Mt.

Figure 62 - Front View of Block Terrace on South Side of Red Rock Ridge

The block terraces on the northwest side of Roman Four Mountain are, broadly speaking, stagnant remnants of the nearby valley glacier. This is indicated by the proximity of the valley glacier, by the relation of the block terraces to the projected profile of the valley glacier, and by the fact that the block terraces slope in the same direction as does the valley glacier. It is not known whether the block terraces were derived from one or more fringing glaciers which might have existed in this area immediately after the withdrawal of the valley glacier or whether they were derived directly from the valley glacier without an intervening fringing glacier stage. An analysis of the distribution of submarine moraines might solve this problem. The block terraces owe their location to the presence of ravines in the bedrock cliffs immediately above them. More blocks and snow accumulated at the foot of these ravines than elsewhere.

The block terraces found elsewhere are probably the stagnant, shrunken remnants of fringing glaciers. This is suggested by their proximity to fringing glaciers and by their similarity to moraine-veneered fringing glaciers.

Block terraces similar to these can also be formed by the ablation of snow slopes covered with talus. If the initial inclination of the snow slope is the same as that of the talus, the resulting terrace flat will be horizontal; if the inclination of the snow slope is less steep than that of the talus, the terrace flat will slope forward; and if the snow slope is steeper than the talus, the terrace flat will have a backward slope. If the present positions of the termini of the glaciers around Marguerite Bay are in part the result of a recent readvance, as suggested above, some of the block terraces may have resulted from the ablation of talus-buried snow slopes.

The regularly sloping surfaces of these block terraces prove that the blocks did not reach their positions under present-day conditions. The blocks are too far from the cliffs to have reached their positions individually under present-day conditions, and had they been deposited by landsliding under present-day conditions the surfaces of the terraces would be much more irregular (McConnell and Brock, 1904, p 9). They must, therefore, have been brought to their present positions at an earlier date by the movement of the fringing and valley glaciers from which the terraces were derived and/or by the sliding, rolling, and ricochetting of blocks down steep snow and ice slopes which may have existed at an earlier time at the foot of the cliffs. The fact that the margins of the block terrace on Neny Island are somewhat higher than the central portion is what would be expected if the blocks came from the ravine above the terrace.

As deglaciation in this area continues, the ice cores in these block terraces will shrink, the block terraces will decrease in height, talus will progressively bury them, and finally with the disappearance of the cores the blocks will be let down as superglacial moraine on sub- and en-glacial moraine. Whether a block terrace or a block field finally results depends upon the thickness of the morainal material and on the height of the terrain beneath the block terraces and on the height of the adjacent areas (Fig. 63). These block terraces are the result of stagnation and are an intermediate stage between actively moving glaciers and ground moraine.

A feature described by Taylor (1922, p 36), which the writer believes was formed in the same way as these block terraces, was found at the eastern extremity of the Kukri Hills in the McMurdo Sound area. It is called a "talus delta" by Taylor, and has a terrace flat and slope; it is composed of blocky material, and there is a couloir above it. Taylor believes that the blocky material was transported down the couloir and deposited in front of it by running water. Apparently another example was found at Mount England. It is described by Taylor (1922, p 35) as follows: "There was a considerable bulk of water at times in these couloirs, for a large fan or delta a couple of hundred yards across had accumulated on the lower slopes of the cliffs. The front of this delta seemed to have been truncated by the debris falling into the sea at a period when the harbour was free from ice." The presence of the terrace flats and slopes makes it unlikely that they are fans. It is extremely doubtful that they are deltas, as there is no evidence of the former existence of standing water in the area.

ALLUVIUM

Fine-grained alluvium was seen on snow which veneered the modern beach on Neny Island. This material was deposited by streams which obtained it from the talus above the beach. Ice crystal impressions were found, and it had sunk into the snow due to solar radiation. Alluvium was also seen on the modern beach at many places. It was either deposited directly onto the beach by streams running from the talus or it was let down onto the beach from a snow cover. When the bay ice broke up and there was open water, waves and shore currents undoubtedly removed the alluvium. It may also have been removed by wind.

An alluvial fan is found on the north side of Neny Island. It is surrounded on three sides by talus and on the fourth by the ocean (Fig. 64). About 200 feet wide where it terminates along the strandline, its apex is about 110 ft above sea level. The fan rests on bedrock, talus, and on both elevated and modern beach deposits. The fragments of which

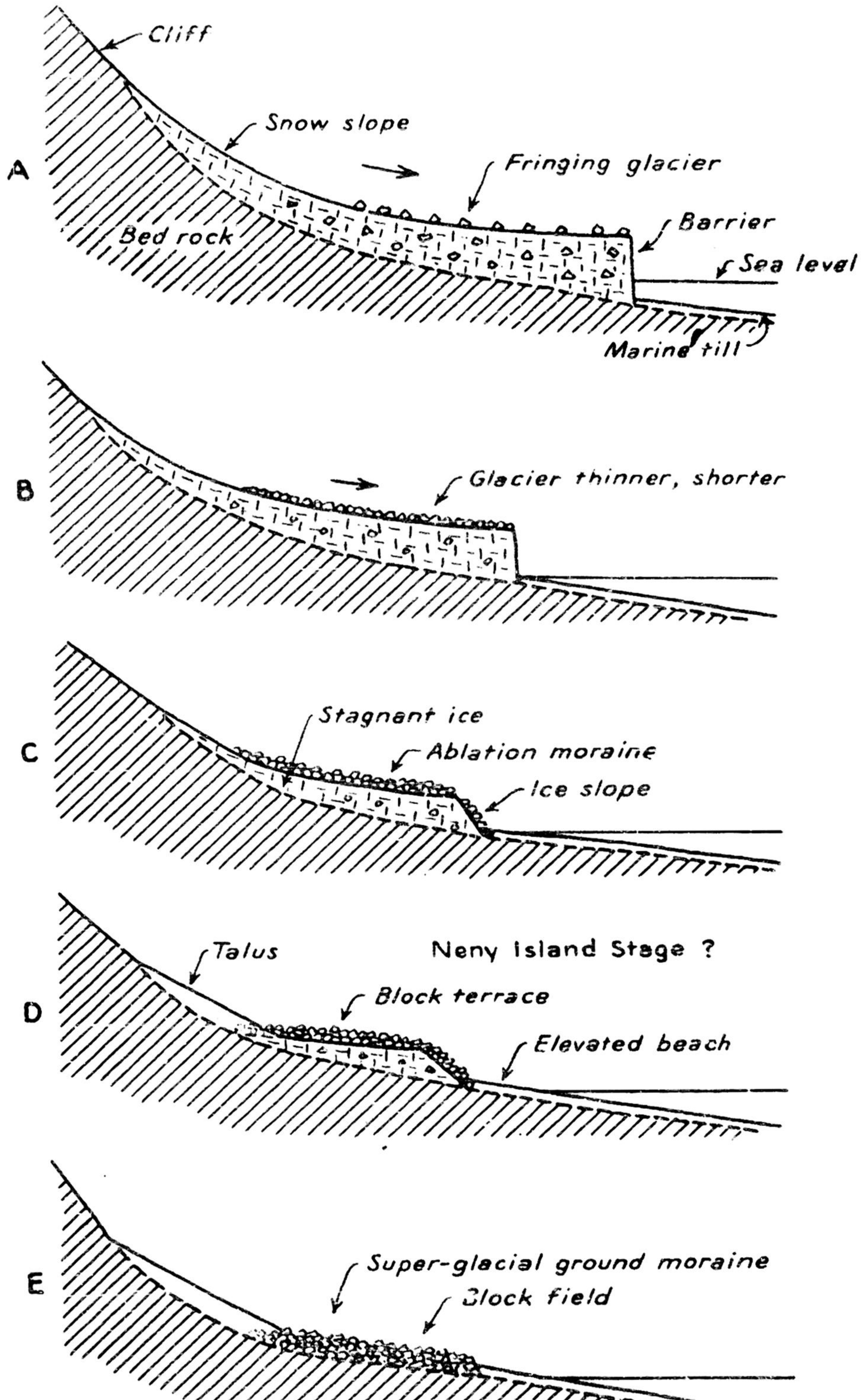


Figure 63 - Diagrammatic Sketches Showing the Formation of Block Terraces

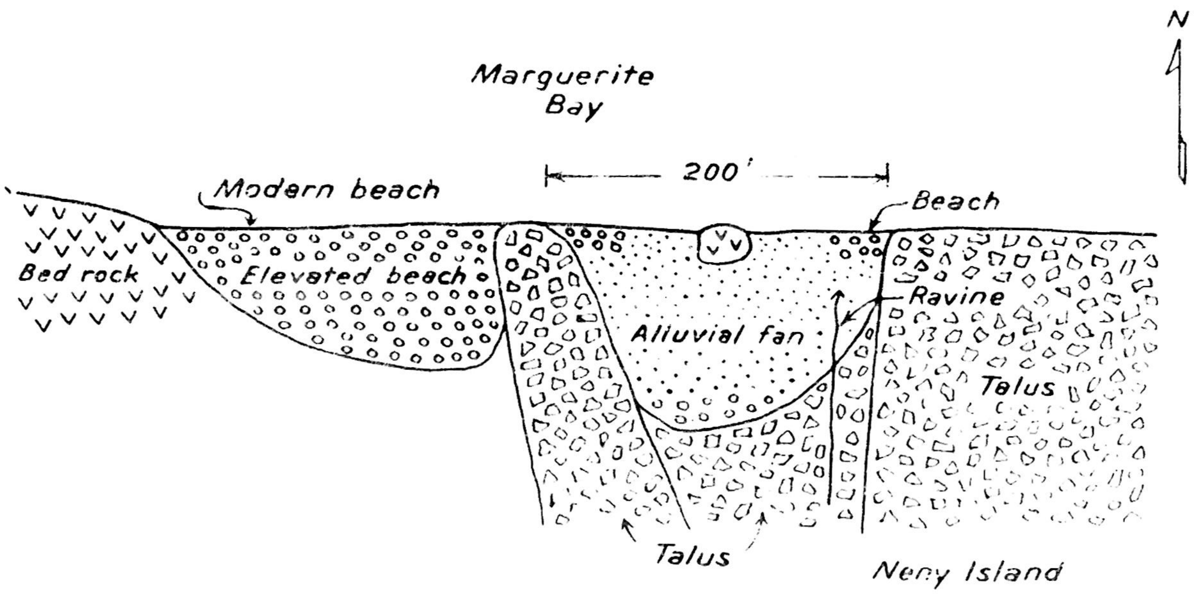


Figure 64 - Alluvial Fan on North Side of Neny Island

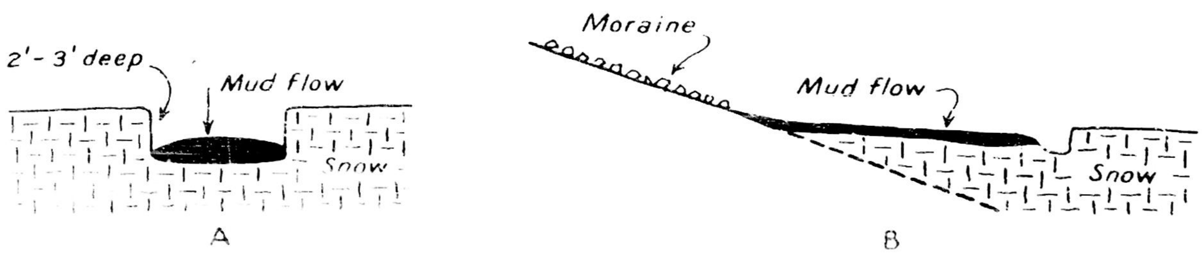


Figure 65 - Mud Flow Snow Trenches Resulting From Solar Radiation, Red Rock Ridge

it is composed are only slightly rounded, and those at its terminus are between one and four in. in diameter. Gullies margined by poorly developed levees are found on it. Surface irregularities suggest that some deposition took place on an irregular snow cover (Nichols, 1937, p 403). The slope of the fan near its apex is approximately 18° and here erosional gullies are common. Talus trenched by a ravine is present above the apex. Depositional topography is almost everywhere present lower than 60 ft above sea level. A few talus fragments are found on the fan. The fan owes its existence to three principal factors: (1) Little talus is formed where the alluvial fan is found because of the topography and perhaps because of the characteristics of the bedrock which is found above the fan. (2) The fan is on the north side of Neny Island where insolation is strongest and where, consequently, the most melt water is formed. (3) A col is located above the fan, between the two principal peaks of Neny Island. The bottom of the col slopes northward and the melt water formed in it is therefore funneled downward to the area where the fan is found.

MUD FLOWS

Small mud flows were seen in January on the south side of Neny Fjord between Bingham Col and the western end of Red Rock Ridge. The mud was derived from morainal material and the water presumably came from melting snow or ground ice. These flows ran out on a snow cover, were several feet wide, and due to solar radiation had sunk into the snow as much as 2 or 3 ft (Fig. 65).

AVERAGE THICKNESS OF ANTARCTIC CONTINENTAL ICE-CAP

Considerable data have been collected on the depth of the break in slope of the Antarctic continental terrace. Arctowski (1900, p 440) of the Belgica Expedition found it at about 1800 ft in West Antarctica. Drygalski (Priestley, 1923, p 58) reported it to be at 2250 ft. The break in slope in the Ross Sea area on a basis of the bathometric data obtained by the Second Byrd Antarctic Expedition, 1933-1935, appears to be at roughly 1600 ft (Roos, 1937, pp 576-581), while an analysis of the data on Charts Nos. 6654 and 5412 published in 1946 by the Hydrographic Office, U.S. Navy Dept., indicates that in another part of the Ross Sea it is also in the neighborhood of 1600 ft. On the west side of the Palmer Peninsula it is at approximately 1600 feet (U.S. Navy Dept., 1939, H.O. no. 5411). A fathogram obtained by Dietz (1952, Fig. 6) in the Indian Ocean sector of the Antarctic at approximately 66°40'S, 73°5'E shows the break in slope at about 1800 ft; and another fathogram obtained by U.S.S. Currituck on U.S. Navy Operation Highjump, 1946-1947, between

64°13.2'S, 66°45.2'W and 64°22.7'S, 66°55.9'W shows it at approximately 1500 ft (Fig. 66).

The above data indicate that the average depth of the Antarctic break in slope is approximately 1600 feet. The world average depth of the break in slope obtained from thousands of charts covering all parts of the world is 432 feet (Shepard, 1948, p 143). That of the Antarctic is, therefore, much deeper than the world average and indeed it is said to be the deepest in the world (Shepard, 1948, p 141). Arctowski (1900, p 440) was the first to suggest that the great depth of the Antarctic shelf might be due to submergence. Priestley (1923, pp 57-58) believes that the submergence is due to the weight of the existing ice-cap. Glacial erosion on the shelf and diastrophic movements unrelated to glaciation may also account in part for the great depth.

The thickness of an ice-cap necessary to depress the earth's crust any given amount can be roughly calculated. If it is assumed that the great depth of the Antarctic break in slope is due to the weight of the ice-cap and not to glaciation or to diastrophic movements unrelated to glaciation; and if it is assumed that its depth prior to glaciation was the same as that of the present world average for the break in slope (436 feet); and if, further, the specific gravity of ice is taken as 0.92, that of the plastic subcrustal material, whose movement away from the glaciated continent caused the depression as 5.00 (Daly, 1934, p 138) and the present depth of the break in slope as 1600 feet; then calculation shows that the average thickness of the Antarctic continental ice-cap is approximately 6300 feet.

If, on the other hand, it is assumed following Dietz and Menard (1951, p 1994) that the break in slope was formed by breaker action at about 30 ft and that its present position is due solely to the weight of the ice, then similar calculation shows that the average thickness of the ice-cap must be about 8500 ft.

Joerg (1936, p 462) from a study of the photographs brought back by Ellsworth and Hollick-Kenyon after their flight across West Antarctica concluded that, "in this tapering projection of the continent between Weddell and Ross Seas, the interior of the ice cap, unlike its counterpart of the same size in Greenland, does not completely mask the underlying topographical features." This suggests relatively thin ice. However, nothing is known of the relief of the buried bedrock topography in this area. If it is similar to that of the topography of the Palmer Peninsula the ice might be several thousand feet thick in places. Gould (1940, p 839) states that, "the structure of the continental margin about the head and the west boundary of the Ross Sea, at least, is not one that leads to the conception of a continental ice sheet of great thickness." He shows

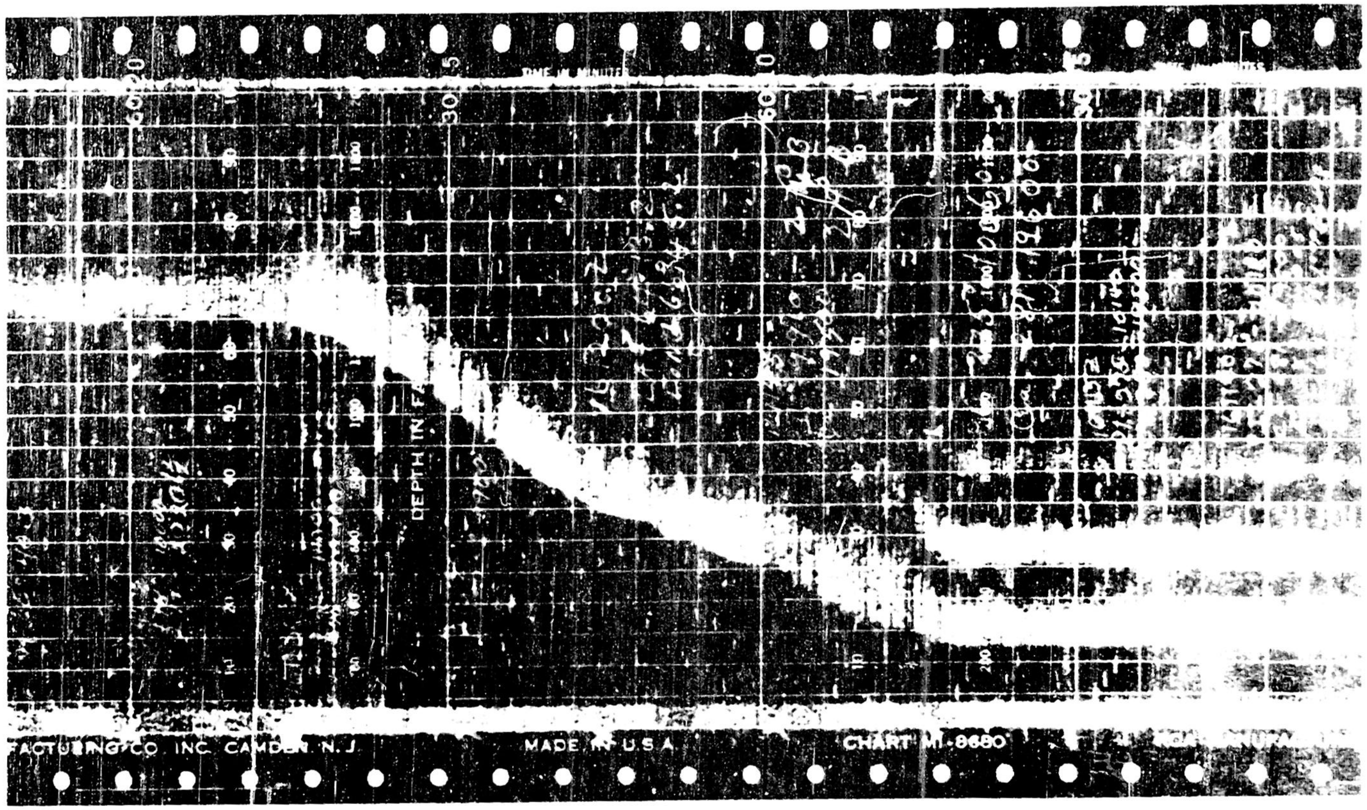


Figure 66 - A Fathogram Taken by the USS Currituck Showing the Break in Slope to be at 1500 Feet Near Latitude 64^0 13.2'S and Longitude 66^0 45.2' W

the inland ice to be approximately 3000 feet thick south of the Ross Shelf Ice (Gould, 1940, Fig. 3). No definite data exist on which to determine the thickness at still greater distances from the Ross Shelf Ice, nor can the figure of 3000 ft be assumed to have any real accuracy. In discussing the thickness of the inland ice, David (1914, p 614) writes, "It has been suggested that the very strong local variations in magnetic declination, proved by Eric N. Webb of Dr. Mawson's Australasian Antarctic Expedition, show that the ice-sheet on the magnetic pole plateau is of no very great thickness, as had the ice-sheet been many thousands of feet in thickness the tendency would have been to smooth out these curves." This statement has been interpreted to mean that the ice in this area was thin (Flint, 1947, p 49). Because the magnetic stations which Webb (1913, pp 648-651) occupied were several miles apart, Prof. Francis Birch, Harvard University, tells the writer that on a basis of these magnetic data there is no justification for assuming that the ice-cap is less than 5 miles thick.[1]

With regard to the thickness of the Antarctic continental ice-cap Debenham (1945, p 19) says, "The thickness of the inland ice is probably not so great as its extent would suggest. No direct measurements have been made, but from an examination of the outlet glaciers, it appears unlikely that the sheet is ever more than 2000 ft thick except in basins, and in general is much thinner, a conclusion which is confirmed by the fact that many hundreds of miles inland from the coast the ice sheet appears to follow closely the form of the underlying ground." It must be acknowledged that very little of a detailed nature is known about the thickness of the inland ice. Detailed geophysical studies are in order. The great depth of the Antarctic continental shelf suggests, however, an average thickness of several thousand feet for the ice-cap.

HIGHLAND ICE

More than 75 percent of the area is covered with permanent ice. Highland, snowdrift, shelf, and island ice; valley, piedmont, tidewater, cliff, hanging, cirque, reconstructed, outlet, wall-sided, strandflat, transection, and fringing glaciers are common.

Highland ice veneers the uplifted erosion surface on the Palmer Peninsula from approximately 63°30' S to the point where the peninsula joins the mainland, a distance of over 600 miles (Figs. 6, 67). In general, it is between 200 and 300 ft thick.[2] It is not thick enough, however, to conceal completely all the underlying bedrock irregularities, as

[1]Personal communication.
[2]Personal communication from Mr. William R. Latady

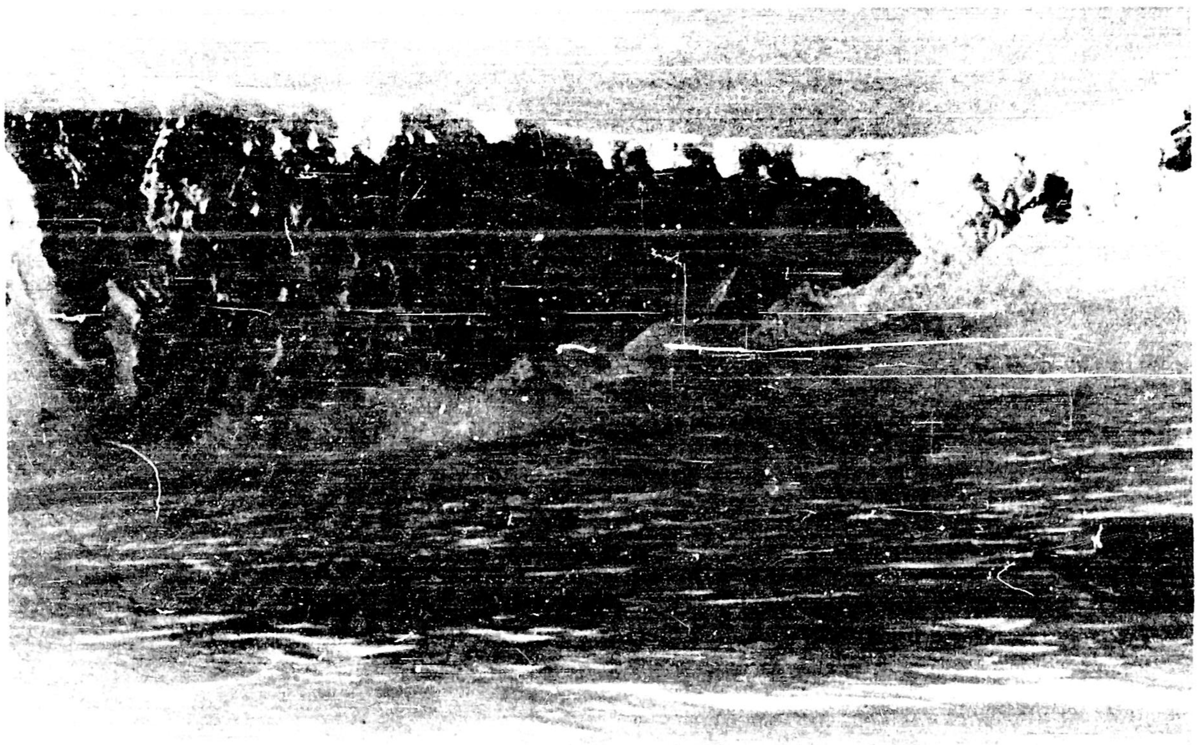


Figure 67 - Highland Icecap and Outlet Glacier
East of Stonington Island

small, ice-covered, domal mountains project above the uniformly flat level of the highland ice. In many places the highland ice terminates at the edge of the plateau in a vertical or nearly vertical ice cliff; here great masses of ice occasionally break off and cascade down to the piedmont, valley, cirque, and other glaciers below. At other places where the mountain slope below the edge of the plateau is presumably less steep and, perhaps, where the highland ice slopes more steeply towards the edge of the plateau, the upland ice flows off the plateau and down the steep mountain slope as a highly crevassed outlet glacier (Figs. 10, 67). At the present time, no appraisal can be made of the percentage of ice which leaves the plateau by means of the outlet glaciers or by falling from the ice cliffs at the edge of the plateau. In places, there is a succession of huge crevasses parallel to and near the edge of the plateau (Figs. 8, 9). These appear to be larger and more numerous where the highland ice slopes more steeply toward the edge. The ice cliffs at the edge of the plateau, the highly crevassed outlet glaciers, the steep bedrock slopes leading up to the plateau, and the marginal crevasses in the highland ice make it impossible in most places for men with dogs and equipment to reach the plateau.

PIEDMONT GLACIERS

Piedmont glaciers are found in the Marguerite Bay area (Fig. 68). Between the mountains and the strandline, there is an almost continuous fringe of ice from Red Rock Ridge south to Cape Jeremy. This ice fringe, where it is fed by valley and outlet glaciers, is a piedmont glacier. In other places, where it is of local origin, it is a fringing glacier. Piedmont glaciers are also present along the east coast of Alexander I Island, north of the shelf ice in King George VI Sound (Fig. 69). The so-called Wordie Shelf Ice appears to be in part, at least, a piedmont glacier, and the Northeast Glacier, north and northeast of Stonington Island, is also one.

The piedmont glaciers have steeper slopes than the highland ice but not as steep slopes as most of the valley, cirque, and cliff glaciers. In places, they are greatly crevassed (Figs. 69, 70). Small domes found on the Northeast Glacier and on other glaciers are due, no doubt, to bedrock highs. Commonly these glaciers push out far enough into the ocean so that large bergs break off from them. Progressive deglaciation has not reduced the area of the highland ice although presumably did affect the thickness. The action has, however, greatly reduced both thickness and area of the piedmont glaciers.

The Northeast Glacier (Fig. 2) has a central zone running up and down the glacier so greatly crevassed that it is practically impassable The areas marginal to this zone have only a few narrow crevasses and

Figure 68 - Northeast Piedmont Glacier in Background and Stonington Island in Foreground

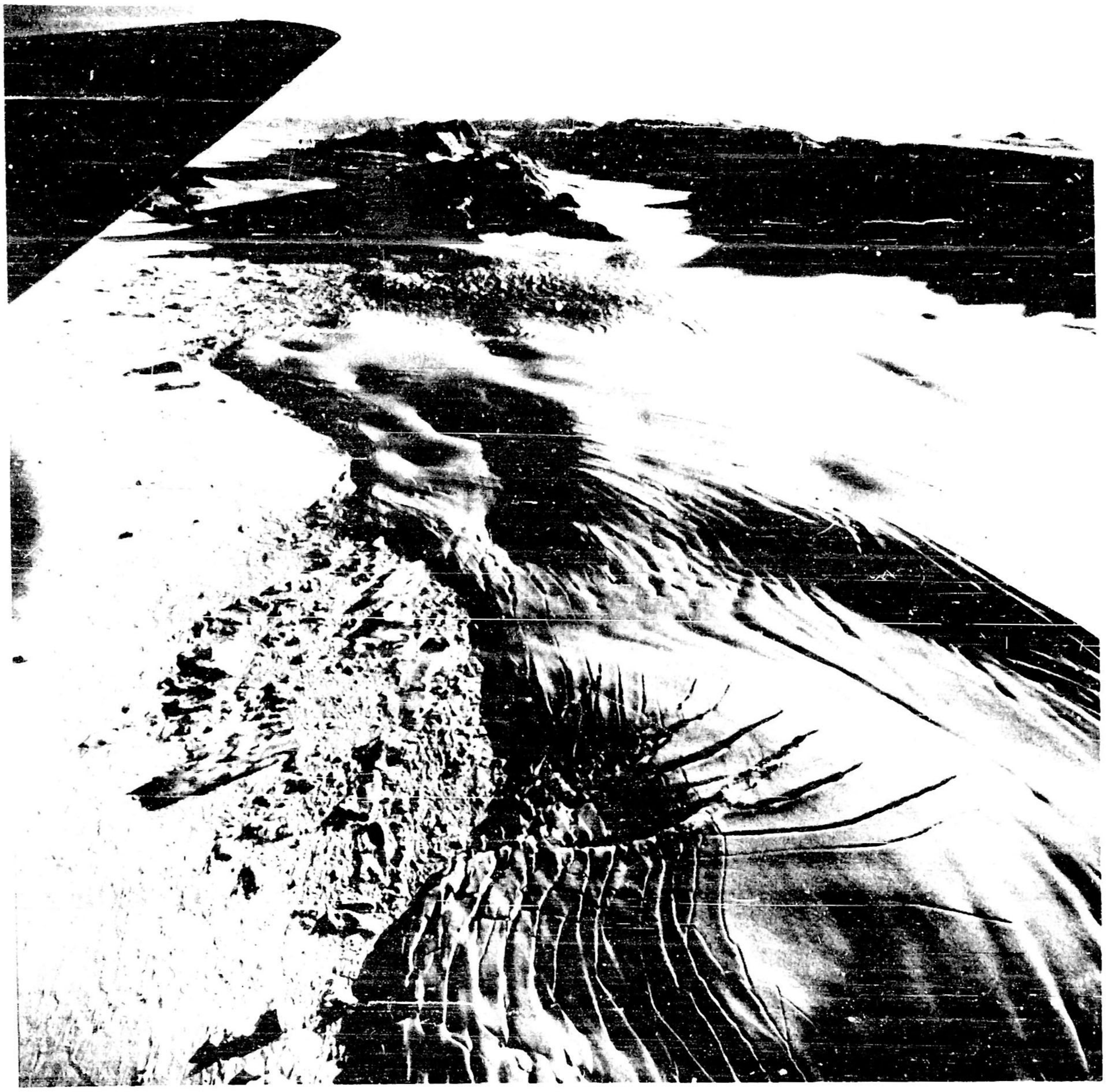


Figure 69 - Piedmont Glacier and Barrier, Alexander I Island

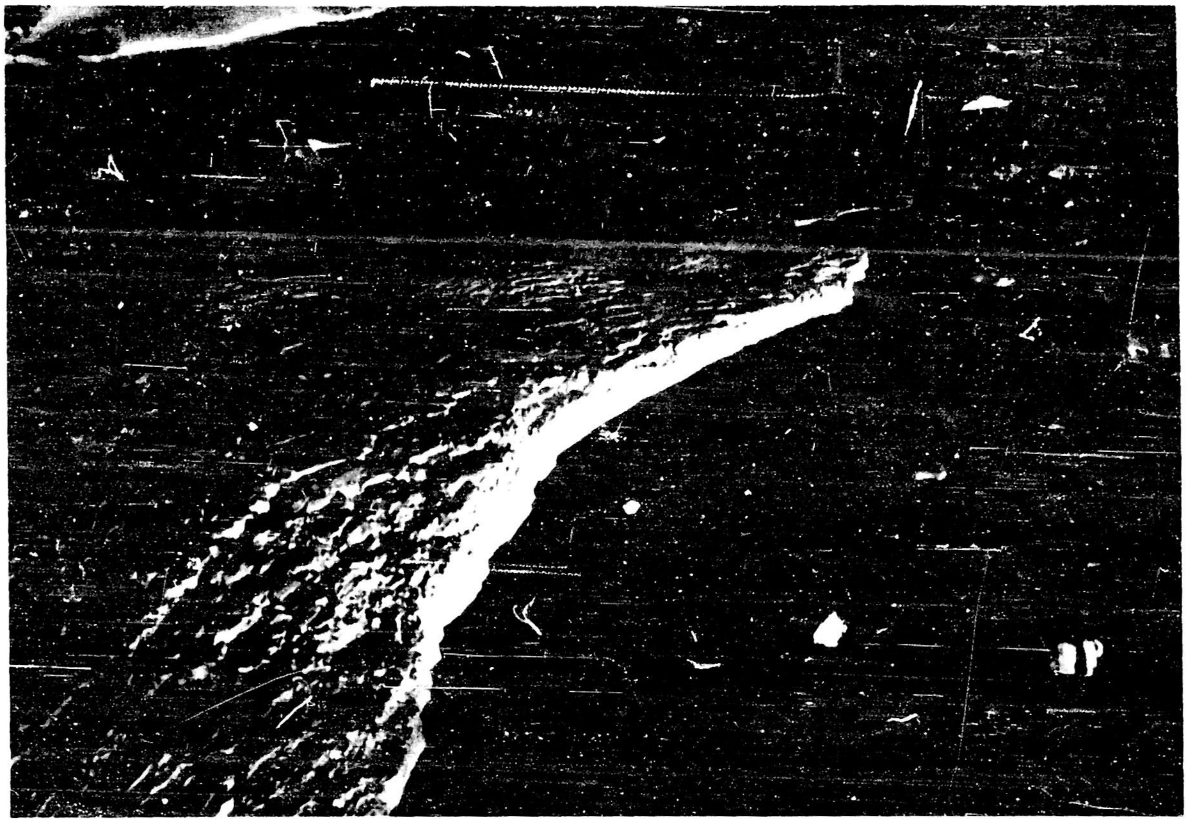


Figure 70 - The Crevassed Central Zone of the Northeast Glacier and Its Barrier During Period of Open Water

travel here is not difficult. An area of sea ice, everywhere covered with fragments of glacial ice, is found in front of the crevassed zone. This brash and growler ice delta, as it may be called, extending from the barrier outward for hundreds of feet, is characterized by an irregular, hummocky topography, and by indications of pressure (Figs. 71, 72, 92G). The barrier adjacent to this area is irregular and, in places, collapsed because of the prevalence of crevasses. There is no area of broken glacial ice in front of the marginal areas. The brash and growler ice delta formed as follows: Masses of ice fell from the crevassed barrier either onto the sea ice or into open water, and ice broke off from the glacial toe and floated upwards. The distance between crevasses controlled the size of these masses. The ice which fell was broken by the force of impact into fragments of various sizes, and the masses which floated up from the glacial toe also broke into smaller pieces. During and following this, the glacier continued to move forward and outward, pushing the ice fragments in front of it. Later, another mass of ice fell from the barrier. The continuous forward motion of the glacier pushed this ice outward while the fragments formed earlier were pushed still farther out; the sea ice beneath the fragments thickened, and it must have grown progressively thicker with increased distance from the barrier. The thrust of the glacier as it moved into the field formed pressure ridges, cracks, and folded bay ice. Where the glacier moved most rapidly, the fragments were pushed farthest out into the bay and the area was widest. It was formed, therefore, by a discontinuous collapse of the crevassed barrier and by a rapid, continuous forward motion of the glacier while the barrier remained at essentially the same place. The great size of the ice delta strongly suggests that the glacial ice in the outer parts of the delta floated to its position during the period of open water and that it was later frozen in by the sea ice. The delta appears to indicate a movement of several hundred feet per year for the Northeast Glacier. If the barrier is farther seaward during the winter because of protection by the bay ice, additional movement is indicated, suggesting that this part of the glacier is either afloat or nearly so. Knowles found one of the marginal areas of the Northeast Glacier to be moving at an average rate of 0.25 foot per day (Knowles, 1945a, p 174). Great differential motion exists, therefore, between the rapidly and slowly moving parts of this glacier. Whether this rapid movement of the crevassed central zone is due to a greater depth to bedrock, to a steeper bedrock gradient, or to other factors is not known. Many of the icequakes recorded on the seismograph at Stonington Island may have resulted from the calving of the Northeast Glacier.[1]

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[1]Personal communication from Mr. Andrew A. Thompson.

Figure 71 - Photograph of Brash and Growler Ice Field
Next to Northeast Glacier

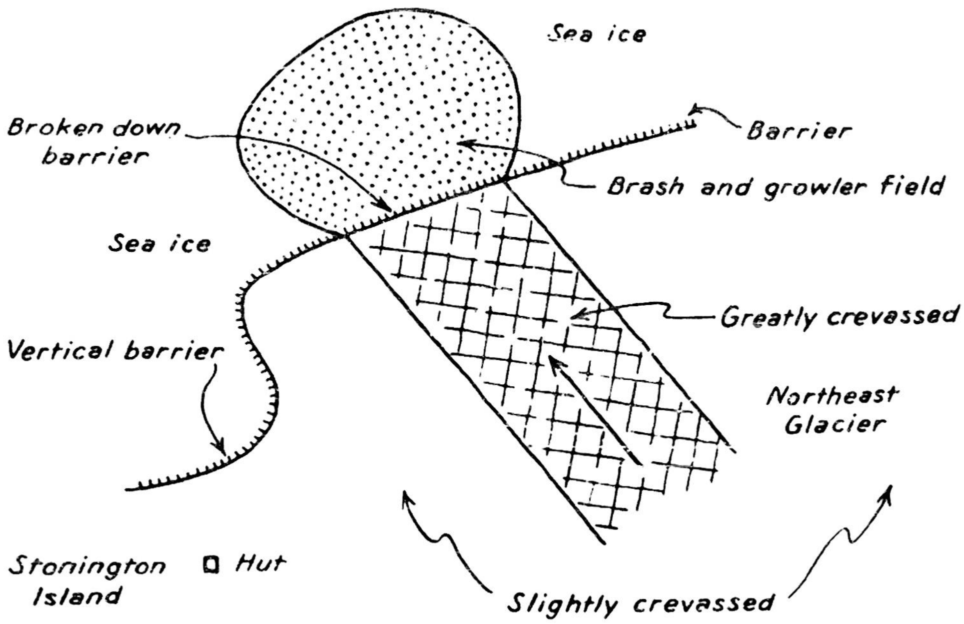


Figure 72 - Diagrammatic Sketch of Brash and Growler Ice Field Formed by Calving From the Crevassed and Rapidly Moving Central Zone of the Northeast Glacier

VALLEY GLACIERS

Neny Glacier, terminating in Neny Fjord, is a greatly crevassed valley glacier It is approximately 5 miles wide near its terminus and is many times as long (Fig 32) Some of its many tributaries join it on grade, while others hang high above it The large icebergs breaking off from the southern part of its terminus, and the folded bay ice found in front of it in this area, prove that it is actively moving (Fig. 10). A zone along its northern margin, extending from the last tributary which enters it from the north down to its terminus, is more badly crevassed than elsewhere and is covered with seracs (Fig 73) Crevasses and seracs are formed in great abundance in an ice cataract located on this tributary glacier just before it enters the main glacier. The zone of crevasses and seracs on the north side of Neny Glacier is derived from this tributary glacier, and it is either an inset or juxtaposed unit of the trunk glacier (Sharp, 1948, p 183) Flat surfaces of wind-packed snow are found between many of the seracs It is not known whether this snow fills the holes between the seracs or only bridges them, although the considerable width of some of these surfaces does suggest that the holes have been filled rather than bridged The true nature of these areas is of considerable interest to those who must travel on them. A short stretch of Neny Glacier terminates on Neny Glacier Island (unofficial name) (Figs. 22, 73). It seems likely that this bedrock area would be surrounded by water if the glacier retreated sufficiently At the present time, however, it is joined to the mainland by the glacier Stonington Island is also joined to the mainland in a similar manner.

The north end of Neny Glacier terminates in a transverse ridge, tens of feet higher than that part of the glacier immediately upstream A mile or more in length, this badly crevassed ridge flattens out and disappears to the south (Figs. 22, 73). Its shape indicates that it is not due to the deposition of wind-blown snow, although wind-blown snow has been deposited in its lee. It is unlikely that it has resulted from differential wastage of the glacier, for there are no factors, such as a protective morainal veneer, which would decrease wastage where the ridge is found It is thought that the ridge was formed because this part of the glacier was thrust by pressure from behind up and over a pre-existing transverse ridge If such is correct, this part of the glacier moved as a rigid, solid unit The existence of bedrock at the extreme northern end of the terminus of the glacier, and the presence of bedrock Neny Glacier Island (unofficial name), suggest that the glacial ridge is due to the thrusting of the glacier over a bedrock high rather than to a readvance of the glacier over a recessional moraine formed earlier.

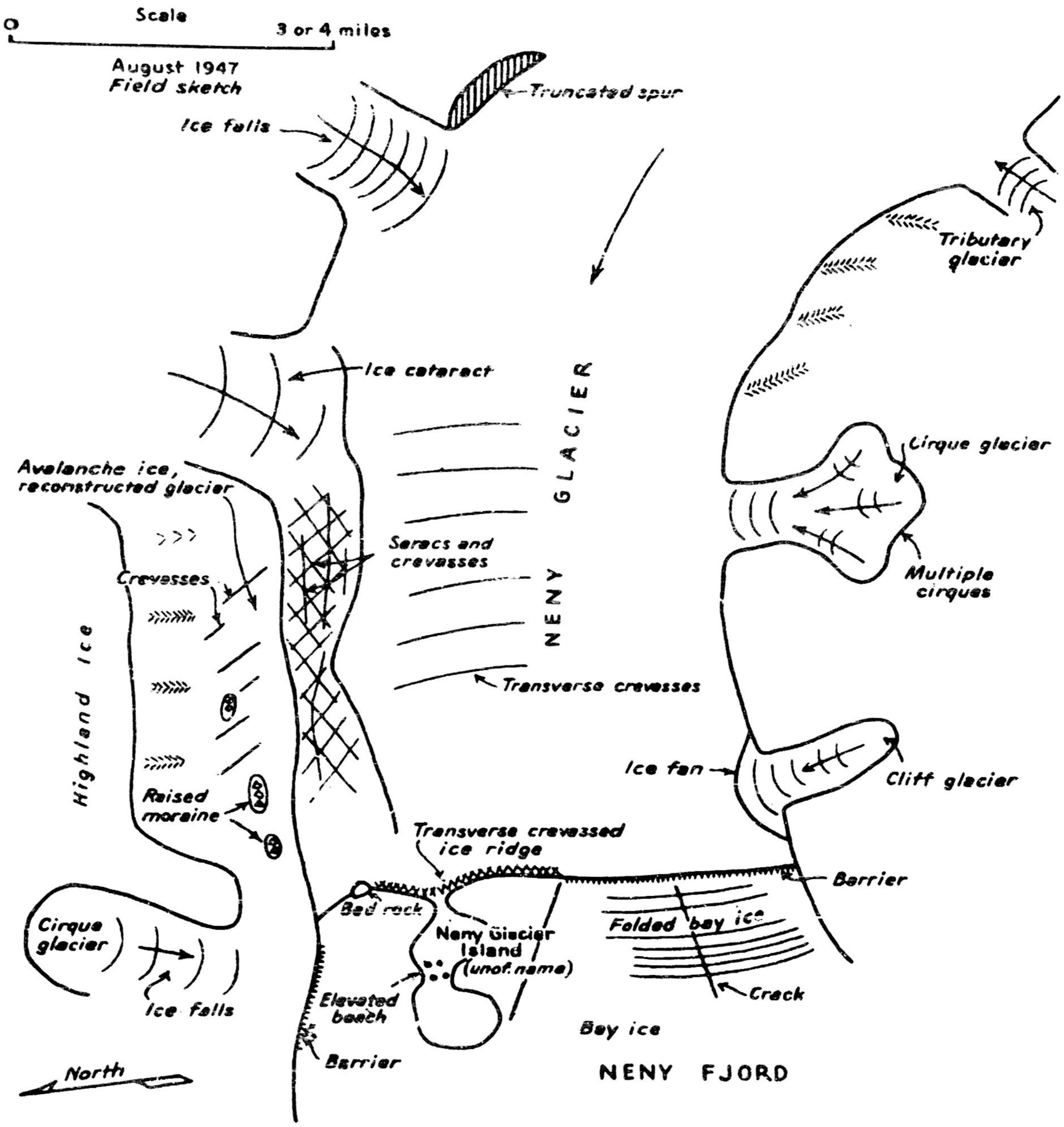


Figure 73 - Diagrammatic Sketch of the Lower Part of Neny Glacier. Folded bay ice, transverse ridge at terminus of glacier, raised moraine, reconstructed glacier, highland ice, and elevated beach on Neny Glacier Island (unofficial name) are shown.

Although high cliffs are found above most of the glaciers in this part of the Antarctic, moraines are not found high above sea level and are not common near sea level This is because the snow line is not far above sea level and the morainal material derived from the cliffs and elsewhere is buried by snow An excellent lateral moraine is, however, found near sea level on the south side of the small valley glacier north of Roman Four Mountain (Figs. 28, 29) This morainal material is not derived from the cliffs above the lower part of the glacier, as the glacier is here separated from the cliffs by a deep moat It falls onto the glacier from cliffs above the upper part of the glacier and is brought to the surface farther down on the glacier by ablation.

FRINGING GLACIERS

Mountains rise almost directly from the sea along much of the coastline of Marguerite Bay Narrow glaciers of local origin commonly terminate in a barrier between the base of t' mountains and the strandline. These glaciers may extend for long distances along the coast. Those studied by the writer are usually only a few hundred yards, measured from the base of the cliffs to the barrier, Fleming (1940, pp 93-98) calls them fringing glaciers and Holtedahl (1935, p 22) calls them strandflat glaciers because he believes that they are responsible for the strandflats on which they presumably rest In one sense they are piedmont glaciers, and were so called by Gourdon (1908), as they are found at the foot of mountains They are not piedmont glaciers, however, in the genetic sense because they are of local origin and are therefore not fed by valley glaciers—they are not expanded or coalescing valley glaciers at the foot of mountains. Among the many places where they are found are the south side of Neny Island, the north side of Neny Fjord, and the south side of Red Rock Ridge near its western terminus. The fringing glacier on the south side of Neny Island is typical of these glaciers It is about 1 mile long, only a few hundred yards wide, and in places its barrier is 50 ft high (Fig. 74)

Proof of their movement is found in the presence of an occasional bergschrund (Fleming, 1940, p 93), in the absence of thick ablation moraines on the surfaces of these glaciers, and in the calving which takes place at the barriers. No evidence of shear or deformation of any kind was noted, however, and blue veins were not seen. Morainal material veneers some of these fringing glaciers, but only clean snow and ice are found on the surfaces of others. The ice seen in the barriers is in general clean, but individual fragments are in places present, and so too are dirt and fragment layers. As might also be expected, debris is commonly found in the ice cliffs of those glaciers whose surfaces are veneered with moraine The dirt layers and other kinds of

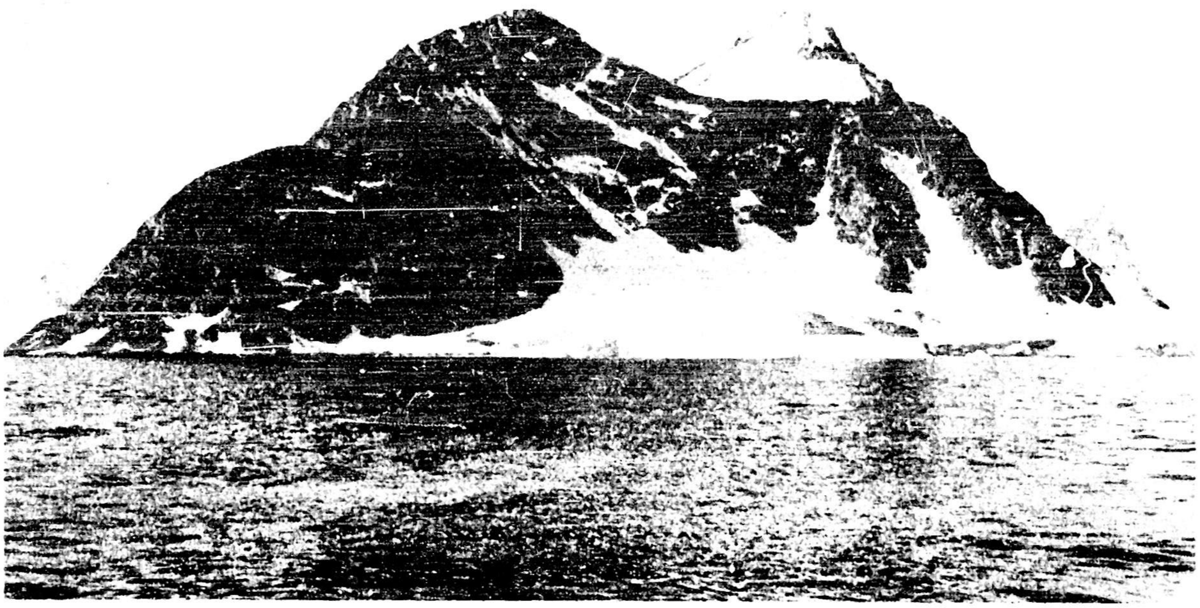


Figure 74 - Fringing Glacier on South Side of Neny Island

stratification seen in the barriers are commonly not parallel to the surfaces of the glaciers, because the glacial surfaces resulting from ablation are not parallel to the stratification of these glaciers Unconformities and cross-bedding were also seen on the barriers (Fig 75) They were formed when ablation surfaces, developed at angles to the bedding, were buried by new snow The cross-bedding is probably also produced by the deposition of snow on topography which changes in slope because of the deposition A consideration of the lengths of these glaciers, measured from cliffs to barriers, and their probable rates of motion indicates that the ice in them is not old and that, therefore, the unconformities represent no great lapse of time The stratification undulates not from deformation but from variations in initial dip Beach gravels are found at the foot of some of the barriers and it seems likely that some of these fringing glaciers have over-ridden beach gravels because of a lowering of sea level, consequent on deglaciation, or a climatic variation Local factors determine the varying heights of these fringing glaciers Below a couloir in the bedrock cliffs above the fringing glacier on the south side of Neny Island, the barrier is higher because here more snow is supplied to the glacier than elsewhere These glaciers, lying below the snow line (Fleming, 1940, p 94), are fed mainly by snow avalanches from the cliffs above them and to a lesser degree by drifting snow and local snowfall In the area around Neny Fjord they are found only at the foot of the high south-facing cliffs, as here insolation is at a minimum A slight amelioration of climate would probably destroy them As indicated above, some of the strandflats were formed by these glaciers The gentle surface gradients of some of the glaciers also suggest that they lie on strandflats

The small fringing glacier on the south side of Red Rock Ridge terminates in the ocean in a low barrier Originating at the foot of high bedrock cliffs, it is veneered with morainal material arranged in a series of ridges and swales which give the glacier a striped appearance (Fig 76) The stripes are straight and run from the cliffs to the barrier Some of the ridges are more than 20 ft above the adjacent swales The morainal material is apparently either thin or absent in the swales and presumably thicker on the ridges It seems likely, although it was not demonstrated in the field, that the morainal ridges are below the ravines on the cliffs, the swales below the rock ridges between ravines Morainal ridges would form below the ravines because the ravines would deliver more snow and fragments to the glacier than the rock ridges and because the ice would probably be better protected against ablation by the thicker moraine at these places

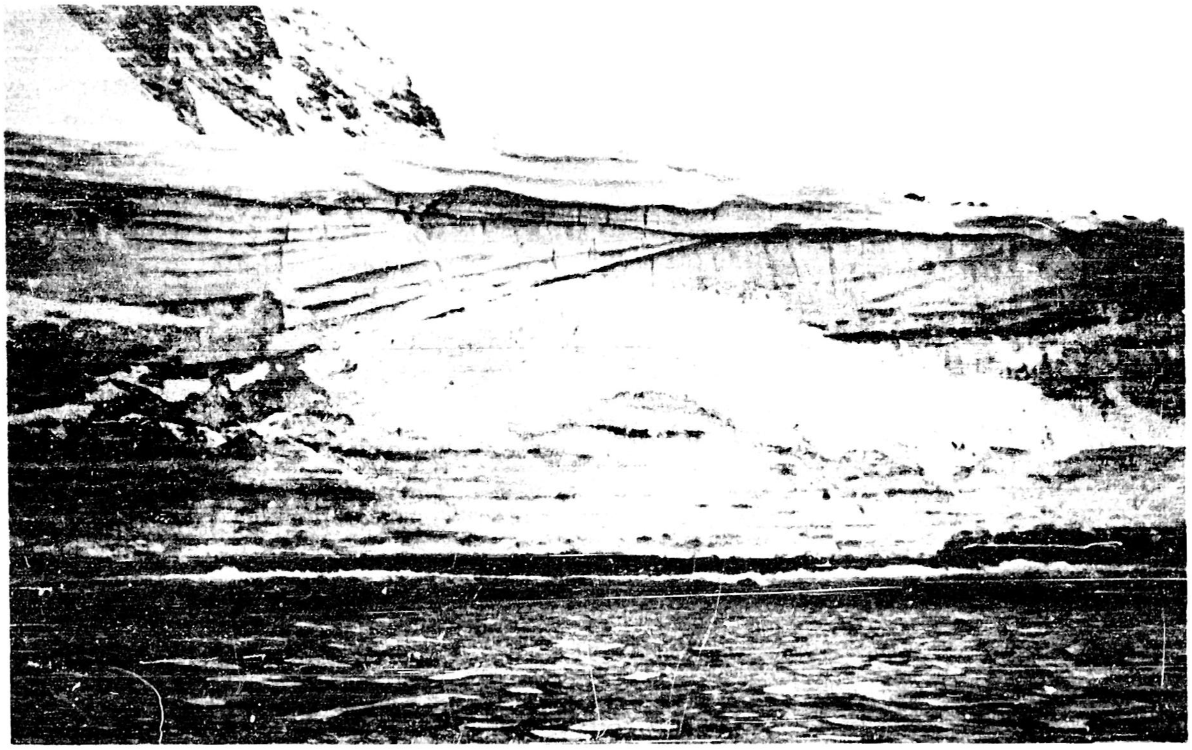


Figure 75 - Unconformities and Cross Bedding on the Barrier of the Fringing Glacier on the South Side of Neny Island

Figure 76 - Striped Moraine on a Fringing Glacier on South Side of Red Rock Ridge. Bay Ice in the Foreground.

RECONSTRUCTED AND OTHER KINDS OF GLACIERS

Between Neny Glacier and the imposing bedrock cliffs to the north, an ice slope sweeps down from the cliffs to the edge of the glacier (Fig 73) This ice slope is nourished in large part by great masses of ice falling from the highland ice-cap above the cliffs That the ice slope moves is proved by its crevasses which are oblique to the slope with their lower ends pointing up Neny Glacier It is, therefore, a reconstructed or avalanche glacier The slow movement of the reconstructed glacier is, therefore, in a direction transverse to the slope and has resulted not from gravitational force acting directly on it but from the shear of the Neny Glacier as it moves past the ice slope

A small cirque glacier is shown in Figure 11 and a transection glacier in Figure 12

ISLAND ICE

Many of the islands of the area have no permanent ice on them Some examples are the Refuge Islands the small islands between Black Thumb Mountain and the Refuge Islands, and several in the Terra Firma group The smaller and lower of these are below the climatic snow line A particularly steep-sided island in the Terra Firma group may be in part above snow line, but it is much too steep for any real thickness of snow and ice to accumulate on it

Several small, more or less symmetrical, dome-shaped islands are located between Mushroom Island and Cape Jeremy (Fuchs, 1951, p 404, also photograph) They are veneered with a carapace of ice which Fuchs found to be 70 ft thick on one of them Small areas of bedrock crop out from beneath the ice on the north side, where solar radiation is strongest The shape of these islands appears to be due mainly to the configuration of the bedrock and, to a lesser degree to the ice carapace which masks the minor bedrock irregularities

A prominent island icecap is found at Mushroom Island A steep, vertical bedrock cliff a few hundred feet in height and of small areal extent is located on the north side of the island, but most of the island consists of a gently curving, convex icecap bounded by a barrier 50 and more feet in height The shape of this island is due, therefore almost entirely to the configuration of the icecap, which appears to be a snowdrift ice slab formed in the lee of the bedrock The shape of the icecap is not due primarily to the underlying bedrock which it apparently more or less completely masks but to the height of the obstacle behind which it presumably formed Fleming has suggested that similar icecaps

farther north owe their development to the former presence of shelf ice (Fleming, 1940, pp 98-100).

SNOWDRIFT ICE

A prominent area of snowdrift ice is found in the southeastern part of Stonington Island (Wright and Priestley, 1922, pp 151-152). Located immediately to the northwest of a line of bedrock knobs which are aligned northeast-southwest, the area is several hundred feet long and somewhat less in width. Five coalescing, smooth, streamlined lobes of snowdrift ice, looking something like plunging anticlines, slope gently away from the bedrock knobs (Figs. 18, 31). This ice pinches out into feather-edged margins on land, and where it reaches the strandline it terminates a short distance above mean sea level in a barrier 10 feet high in places. The barrier is not straight, apparently due to the irregularities of the terrain on which the ice slab rests. It is highest where the ice slab is thickest, and it disappears at the feather edges of the slab. The crests of the lobes slope N.290°E, between 8° and 14°. The sides of the lobes have still steeper slopes and between them are interlobate swales. The snowdrift ice rests on bedrock and on elevated beach gravels, and is therefore younger than the elevated beach gravels (Fig. 77). No data were obtained which indicated that this ice is in motion. On the other hand, its thickness and the flatness of the surface on which it rests strongly suggest that it is stationary (Matthes, 1900, p 190).

One prominent dirt band was seen on the barrier. No opportunity was available to determine whether it was due to eolian or fluviatile action. It was, however, not brought from beneath by glacial movement. Wright and Priestley (1922, p 233) point out that silt bands are common in small snowdrift ice slabs as they are often surrounded by snow- and ice-free areas. The scarcity of silt bands in this ice slab is due to the fact that it is surrounded only by coarse beach gravels and bare bedrock outcrops, neither of which are good source materials for silt bands, and to the fact that the area of the island is not great. The ice exposed in the barrier is massive with little visible stratification. Icicles and ribbon stalactites hung from the barrier on April 30, 1947. The salt water nearby had a surface temperature of 28.6°F and as the mean free air temperature for the month was 25.2°F (Peterson, 1948a, p 7) it seems likely that they were formed not from melt water but from sea water.

That they are snowdrift ice slabs is proved by the following. The long axis of each lobe is aligned N.290°E -N.110°E, and the prevailing wind for the area is southeast (Peterson, 1948a, p 7). The ice slabs, located on the leeward side of bedrock knobs, have a streamlined shape

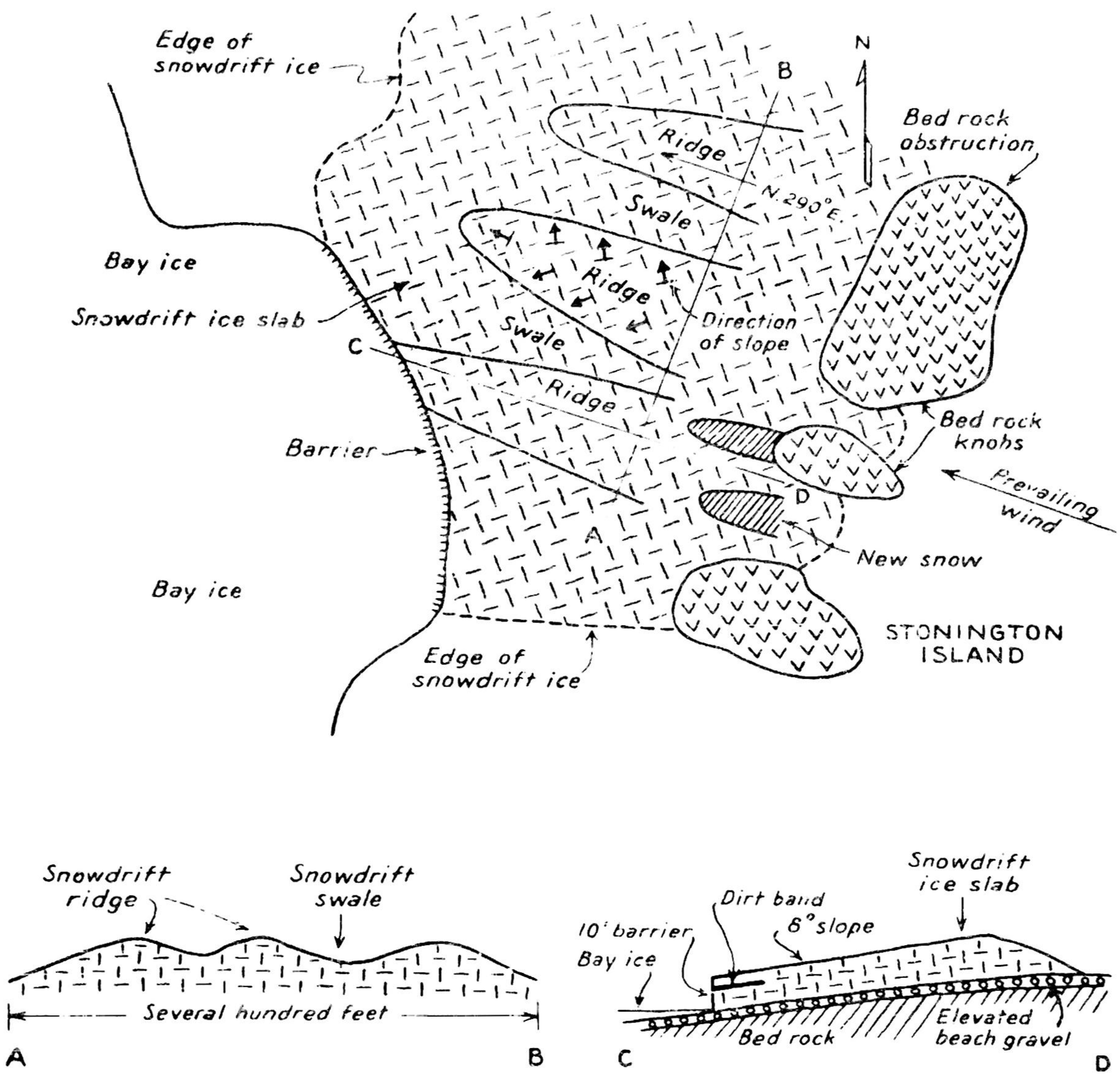


Figure 77 - Diagrammatic Sketches Showing the Snowdrift Ice Slab on the East Side of Stonington Island

and decrease in size with increasing distance down wind from the obstacles. They are similar to the sand shadows formed in back of fixed obstructions (Bagnold, 1942, pp 188-191). Although the major configuration is due to the accumulation of wind-blown snow on the leeward side of bedrock obstructions, some of the minor slopes and surfaces near the knobs are probably due to radiation from the knobs.

It is not known whether they are changing in size or not. If they have been decreasing or only remaining the same in size for some time, a silt band perhaps more prominent than those found elsewhere should be present near the top of the snowdrift ice slab. No such silt band was found. This would seem to indicate that they are still growing. However, no objects dropped by members of the U. S. Antarctic Service Expedition (1939-1941) were seen below the top of the barrier. They appear to be about as large as would be expected behind these obstacles.

Immediately following the deglaciation of this part of the Palmer Peninsula, Stonington Island was completely submerged. Following this, the area rose gradually and continually, due to crustal adjustments resulting from deglaciation, and Stonington Island came into existence. Small snowdrift ice slabs were formed and with the continued rise and increase in size of the island, the ice slabs grew larger. The more northerly lobes were formed first as they rest on higher ground than the others. The lobe which terminates in a barrier will continue to grow as uplift continues.

Snow is blown from the island and permanently lost during that part of the year when there is open water around the island. Men walked on bay ice from the ship to Stonington Island on May 2, 1947 and the ice broke up on February 28, 1948. The bay ice surrounds the island for approximately 9-10 months on the average. More snow is probably blown onto the island, therefore, than is blown off. Because the ice slabs are located close to the windward side of the island, much of the ice in them was probably blown as snow from the bay ice.

Other smaller areas of snowdrift ice are located between the British buildings and this area.

The largest area of snowdrift ice on Stonington Island is found at its northwest end on the leeward side of the island, where there is an area of many acres of this ice (Fig. 78). It has accumulated in the lee of prominent rock obstructions. The surface, much flatter than that described above, slopes away from the obstructions at angles of only a few degrees. Because the rock obstacles are lower to the north, the surface also slopes gradually in that direction. The thinness and flatness

of the terrain on which this ice slab rests prove it to be stationary The slab terminates along the strandline in a barrier which in places is 15 ft high Calving is taking place at the barrier and crevasses appear parallel and several feet in back of it (Fig 79) These are not due to a general movement of the ice slab but only to undermining by wave action and to the presence of the free face of the barrier The snow and ice in a swale between the two southern obstacles are discolored, apparently by running water The Northeast Glacier terminates against the snowdrift ice slab in a snout As the glacier rises rapidly to the north, a swale is located where they meet The barrier of the snowdrift ice slab is continuous with the much higher barrier of the Northeast Glacier Blue veins and silt bands, common in the glacier barrier, are not present in the snowdrift ice barrier

A small snowdrift ice slab resting on elevated beach gravels, extending down almost to sea level and attached to a high bedrock knob, is located at the southeast end of Stonington Island How much of it has resulted from snow deposited on the windward side of the knob by southeast winds and how much by deposition on the leeward side by northwest winds is not known For much of the time it is in the shadow of the bedrock prominence to which it is attached, and it owes its existence in part to the small amount of insolation received

SHELF ICE

In many respects the most interesting ice formation in the area is the shelf ice found in King George VI Sound Stephenson and Fleming (1940), Ronne (1945) and Fuchs (1951) have sledged on it, and the description which follows is based on their writings This ice shelf, approximately 280 miles long, varying in width from 15 to 50 miles has an area of several thousand square miles (Fuchs, 1951, p 400) Forty feet is the best figure for the height of the ice shelf at its northern edge and 30 ft has been reported for its height at the southwest edge If it is assumed that 15 percent of the shelf ice is above sea level (Poulter, 1947 p 170), calculation shows that the shelf ice is approximately 270 ft thick at its northern terminus and about 200 ft thick at its southwestern Poulter noted that the Ross Shelf Ice when studied was thinner at the edge than it was a short distance inward He thought that this was due to marine currents causing a more rapid melting of the bottom of the shelf ice at the edge Fuchs (1951, p 412) found a considerable current flowing toward the southwest barrier and a similar current running toward the northern barrier and believes that a considerable tide runs under the shelf ice These currents should melt and corrade the bottom of the shelf ice and, indeed, Fuchs (1951, p 412) found a place where the shelf ice was very thin near the

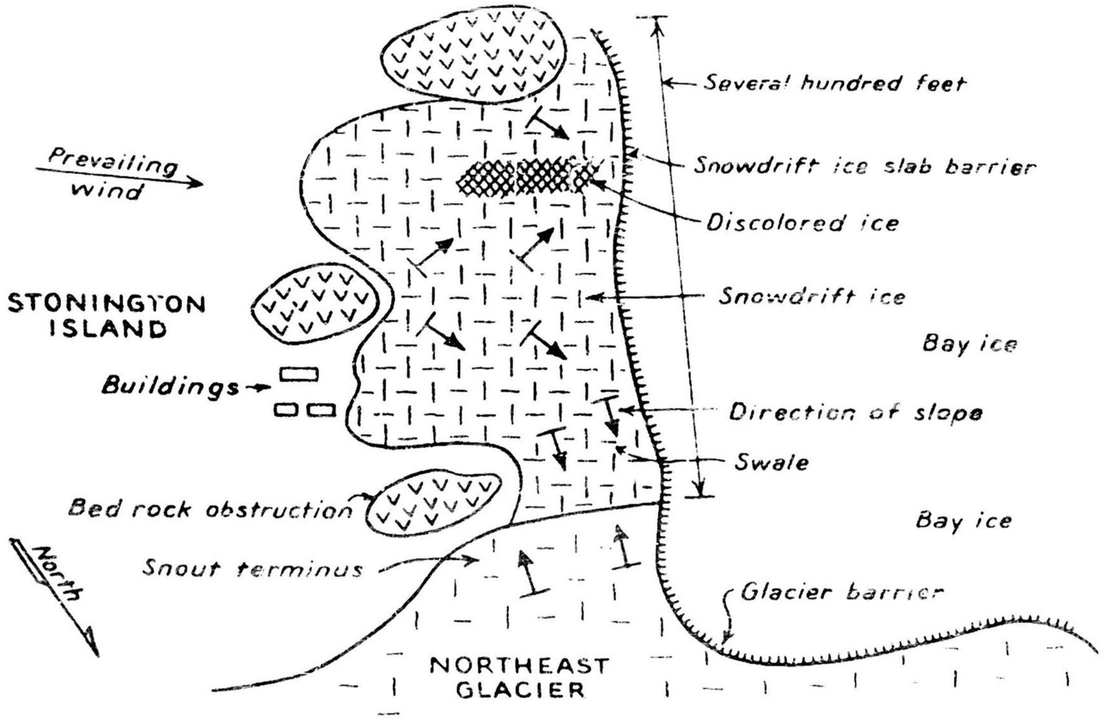


Figure 78 - Diagrammatic Sketch Showing the Snowdrift Ice Slab and Northeast Glacier on Northwest End of Stonington Island

Figure 79 - Barrier of the Snowdrift Ice Slab on the Northwest Side of Stonington Island. Northeast Piedmont Glacier in the Background.

southwestern barrier, apparently due to this mechanism. Ronne (1945, p 21) recorded the elevation of the ice shelf at long distances from the barriers as 150 ft above sea level. These data were obtained with a barometer, and are therefore subject to error. They also suggest, however, that the shelf ice is thinner near the barriers.

The ice shelf is in general a smooth, level, unbroken, featureless surface. This is shown by Figures 5, 6, 7, and 8 in Ronne's (1945) paper. That much of the shelf ice is afloat is indicated by the appearance along its margin of the tidal crack and crumpled ridge which are continuous for long distances, by the presence of salt water in a crevasse a few miles south of 72°00' S, scores of miles from the nearest barrier, and by its prevailing flatness and lack of crevasses. The Sound narrows in the vicinity of 71°30'S and the constriction has caused the ice to pile up somewhat, so that here the ice shelf is higher than elsewhere. The ice shelf is margined by glaciers, snow slopes, and bedrock cliffs. Where glaciers push into the Sound, the shelf ice is folded into anticlines and synclines, broken into crevassed and hummocky areas, and rifts 30 feet deep and up to 1/2 mile wide are formed.

During the summer, large lakes several hundred feet wide, a mile or more in length, and many feet deep are found on the surface of the shelf ice. Melt water streams enter these lakes from the snow and rocks above, and streams run from them into nearby crevasses. The melt water comes from the highlands which margin the Sound and from the melting of the upper layers of the shelf ice. Radiant energy from the sun rather than the thermal energy in the atmosphere is probably responsible for most of the melting. These lakes freeze solid during the cold season, forming thin veneers of lake ice on the shelf ice.

Erratics are apparently not common on the ice shelf, as they were reported only by Ronne and by him at only one locality (Ronne, 1945, p 16).

At one place close to Alexander Island, the shelf ice was considerably thinned by ablation because of the rock dust blown onto the shelf ice from the nearby outcrops.

The ice calderas are perhaps the most interesting and unique geomorphic features found on the ice shelf (Stephenson and Fleming, 1940, p 160). They are bowl-shaped depressions less than a mile in diameter, with in-facing ice cliffs scores of feet high and with gentle outer slopes rising above the ice shelf level. Ice mounds and stacks of diverse origin are found at the bottom. They are well named, for superficially they look like volcanic calderas. Their origin is obscure.

A nunatak more than 1000 ft high, completely surrounded by shelf ice, was found in 1940 in the southwestern part of the Sound by Ronne (1945, p 17). An area of rounded ice hills or swells, all heavily crevassed, is located to the east and northeast of the nunatak. Fuchs (1951) believes that they are similar to Roosevelt Island, southeast of the Bay of Whales (Gould, 1935, pp 1374-1376; Poulter, 1947, pp 169-170), and are due to the presence of rocky islands beneath the shelf ice.

The northwestern branch of Bourgeois Fjord is also filled with shelf ice.

The Larsen Shelf Ice is found along the east coast of the Palmer Peninsula. It is several hundred miles long and in places more than 50 miles wide. The following characteristics and features of this shelf ice have been described and considered by Knowles (1945c) and Mason (1950): the undulating surfaces off the mouths of inlets; the height, thickness, and age; the melt water lakes in the undulating areas; the depression at the junction of the land ice and shelf ice; the fact that where attached to the land or land ice it may be either afloat or aground; and the lenticular holes, crevasses, and rifts.

SNOUT AND CLIFF TERMINI

A glacier that does not reach the ocean but stops instead on land, commonly terminates in the Marguerite Bay area and elsewhere in a curve convex outward in the so-called snout (Wright and Priestley, 1922, Figs. 77, 78; pp 259-261). The snout may be steep or flat (Fig. 80). A vertical barrier extends for miles from Red Rock Ridge on south. About 2 miles south of Red Rock Ridge, however, the barrier is replaced for 200 ft by a snout. Investigation showed that a small area of bedrock cropped out above sea level here and that the glacier terminated on the bedrock outcrop (Fig. 81).

The knowledge that bedrock is usually found at the foot of a snout was used by the writer to locate bedrock along the barrier coastline of Marguerite Bay. The snouts could be seen for long distances and at their foot bedrock outcrops, often snow-covered and too small to be seen for any distance, were invariably found. A snout replaces the barrier of the Northeast Glacier for a short distance just east of Stonington Island (Fig. 82), another is found along the Neny Glacier, and the Northeast Glacier terminates in a snout against a snowdrift ice slab which covers part of Stonington Island.

On first thought, it might seem as if the snout terminus were due to extrusion flow (Demorest, 1942, pp 35-37; Seligman, 1947), but it is

Figure 80 - Snout and Barrier Termini of the Northeast Glacier in the Background and Elevated Beach on Stonington Island in the Foreground

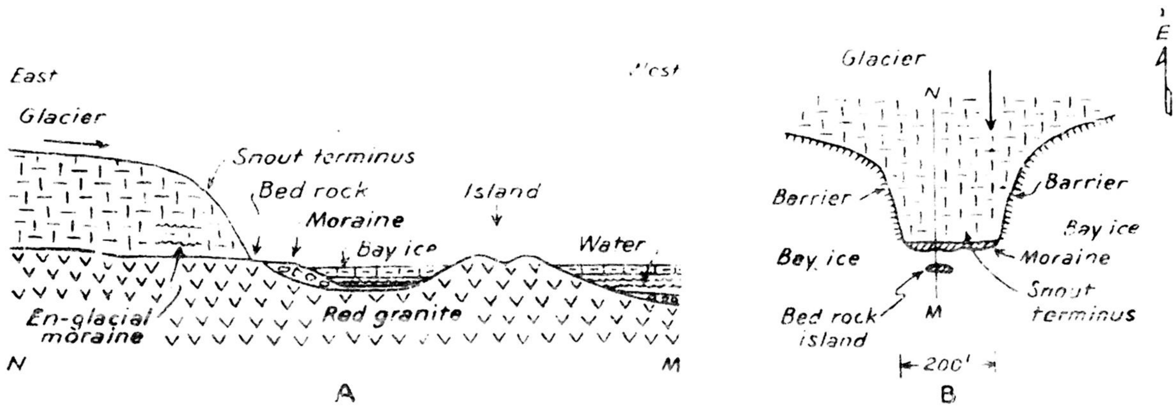


Figure 81 - Snout Terminus a Few Miles South of Red Rock Ridge

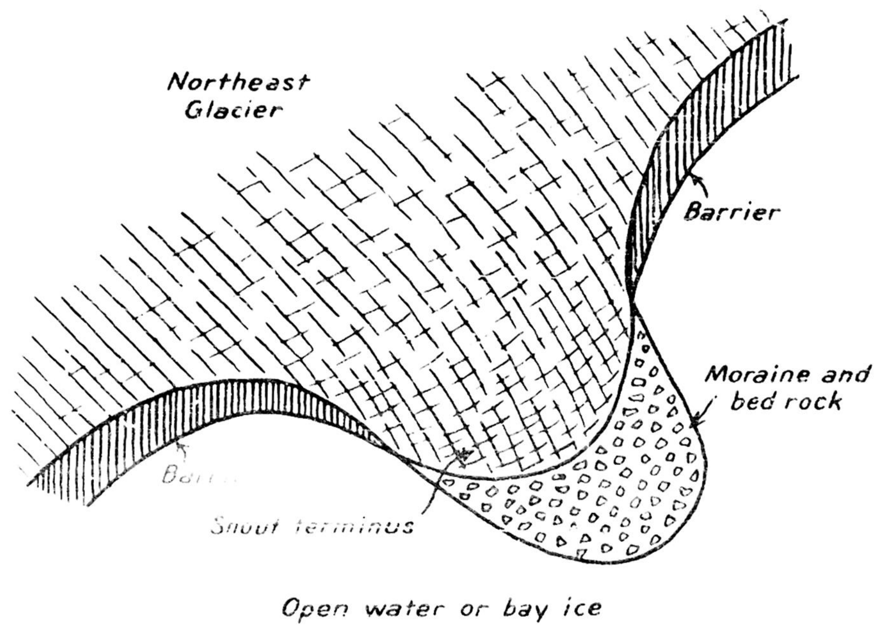


Figure 82 - Snout Terminus of the Northeast Glacier Near Stonington Island

unlikely that extrusion flow takes place in these situations as the ice is too thin and the gradients are too steep. The snout terminus is probably due to: (1) The absence of wave action where the snouts are found. (2) The absence of significant thermal radiation from the rock at the foot of the snouts. (3) More ablation in the upper parts of the glaciers, because of the presence of morainal material, than in the lower parts. (4) The absence of marginal melt water streams acting at the foot of the glaciers. (5) The presence of melt water, warmed by solar radiation, cascading down the termini of the glaciers.

Island icecaps cover some of the smaller islands north of Adelaide Island. The icecaps on the south side of these islands terminate on land in ice cliffs, some of which are scores of feet high (Fleming, 1940, Figs. 1, 5). The fact that these icecaps, terminating on land, have barrier rather than snout termini is perhaps due to: (1) The effect of wave action. (2) The effect of radiation and convection of warm air from bedrock located at the foot of the ice cliffs. (3) More ablation in the lower parts of the icecaps because of the presence of morainal material than in the upper parts. (4) The presence of marginal melt water. (5) The greater absorption of solar radiation by blue ice if the upper part of the barrier is composed of white ice and the lower part of blue ice. (6) The effect of radiation and convection of warm air from the open water below the foot of the ice cliffs. (7) The breaking off of the ice if the ice is moving and if it terminates at a bedrock cliff. The Emmons Glacier on Mount Rainier also terminates on land in an ice cliff, probably partly because of radiation from morainal material at the foot of the ice cliff. Marginal streams also from ice cliffs. The Greenland Icecap east of Thule in general terminates on land with a snout ending. Near the outlet of a recently drained ice-dammed lake, instead of a snout, spectacular high ice cliffs are present, presumably formed by the undercutting of the outlet stream.

GLACIAL READVANCE

The presence of smoothed surfaces, bedrock basins, and the location of the Northeast Glacier, as well as data from Red Rock Ridge, Roman Four Promontory, and elsewhere, prove that Stonington Island was glaciated. Elevated beach gravel is found 70 ft above sea level on Stonington Island (Nichols, 1947a). The island was, therefore, either completely or nearly completely submerged immediately following deglaciation. Since deglaciation, the land has gone up with respect to the sea perhaps 60 or more feet; and yet, in 1948 the barrier of the Northeast Glacier was in places less than 1/4 mile away from the island (Fig. 80). No data were obtained on the rate of uplift. If, however, a rate of 10 ft per century is assumed--and this is twice as rapid

as the present rate of uplift in the Canadian Northwest Territories (Washburn, 1947, p 73)—then it appears that the Northeast Glacier has retreated less than 1/4 mile in 600 years. This seems too slow in view of the rate of retreat between 1939 and 1948 and in view of the rate of retre[illegible]e shelf ice in King George VI Sound. It suggests that the Northeast Glacier, after retreating an unknown distance, may have readvanced to its present position. The beaches on Stonington Island have no features suggesting that they were ever overriden by the Northeast Glacier, and no beach gravels indicating a readvance were seen incorporated in the glacier. Whether this readvance, if real, was due to a climatic fluctuation or to a shoaling of the bay because of uplift, is not known.

Elevated beaches 50 ft above sea level are found on Neny Glacier Island (unofficial name) (Fig. 83) only a few hundred yards from Neny Glacier. The proximity of the elevated beaches and the terminus of the glacier may be due to a readvance of Neny Glacier.

A suggestion that a readvance of the glaciers in Marguerite Bay has recently taken place is afforded by the work of the German and Swedish Expeditions at Royal Bay, South Georgia. A series of measurements made by the Germans showed that the Ross Glacier retreated more than 1 kilometer between August, 1882 and August, 1883. Measurements by Duse showed that the Ross Glacier, between 1883 and 1902, had readvanced more than 1-1/2 kilometers (Nordenskjöld and Andersson, 1905, pp 345-346).

A readvance of the ice some time after the Red Rock Ridge glacial stage is suggested by observations made by Fuchs (1951, p 405) on one of the snow-capped islands south of Mushroom Island. On a 20-foot ice cliff resting on bedrock, two dark layers containing bird feathers, excreta, and rock particles were seen. Above the layers, there was an additional 50 feet of solid ice. During the Red Rock Ridge glacial stage, this area was more heavily glaciated than at any time since, and was perhaps covered with hundreds of feet of ice. Fuchs interprets this section to mean that the ice was less extensive when the birds were living than at a later time when their remains were buried by glacial ice. A thickening and readvance of ice in this area is therefore indicated (Fuchs, 1951, p 405). With this interpretation the writer is in agreement. The glacial sequence for the area follows: (1) Red Rock Ridge glacial stage. (2) Thinning and retreat of the ice to the position occupied when the birds were living. (3) A thickening of the ice and the burial of the bird feathers with or without a readvance on the island, and a thickening and readvance on the mainland where the ice terminated on land.

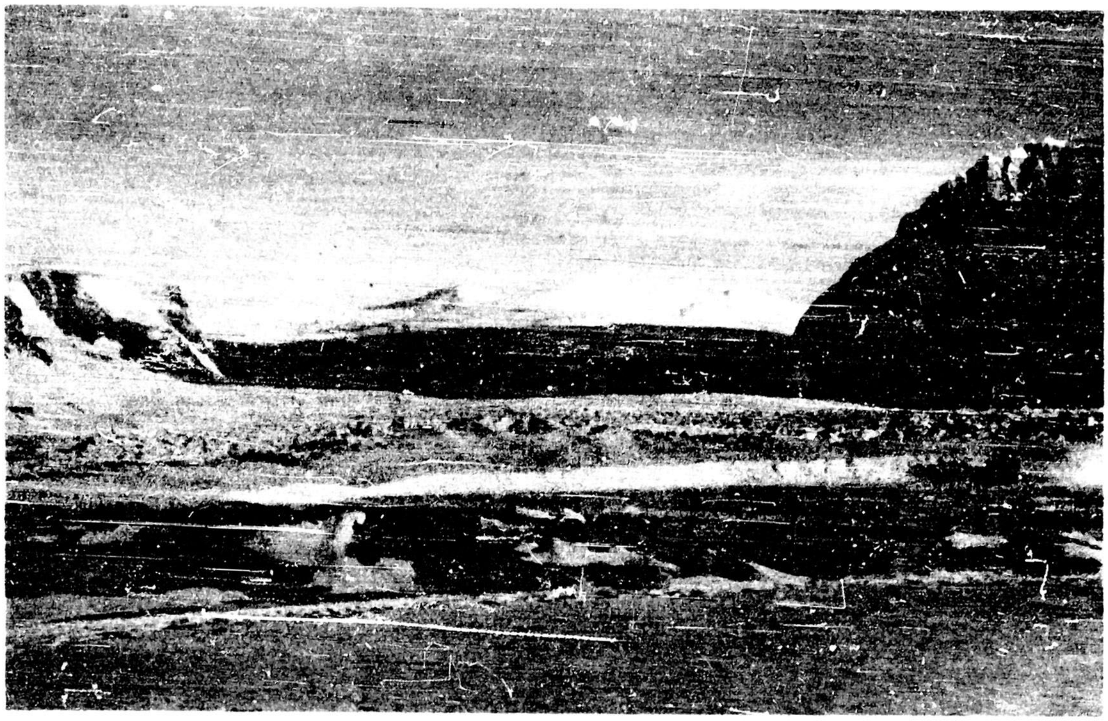


Figure 83 - Elevated Beach Gravels on Neny Glacier Island (Unofficial Name) Which Are 50 Feet Above Sea Level and Only a Few Hundred Yards from Neny Glacier

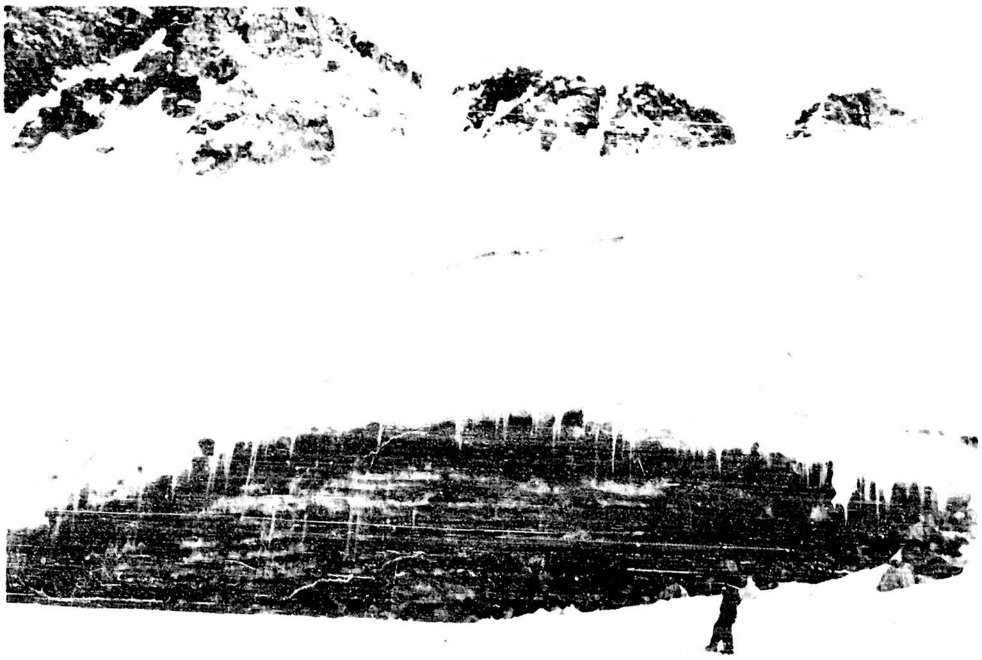


Figure 84 - Photograph Showing the Unconformable Relation Between the Moraine Filled Ice, Below, and the Clean Ice, Above

Figure 85 - Beach Gravels, Below, Buried by the Mushroom Island Ice-Cap, Above

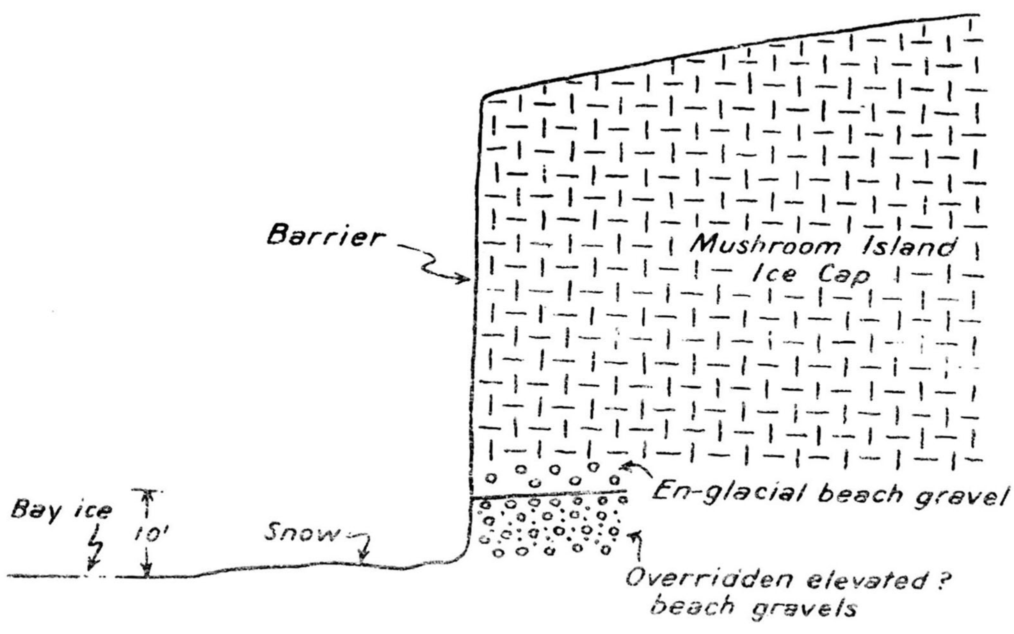


Figure 86 - Diagrammatic Sketch Showing the Beach Gravels Buried by and Incorporated in Mushroom Island Ice-Cap

Figure 87 - Beach Gravels Incorporated in the Lower Part of Mushroom Island Ice-Cap

Figure 88 - Barrier Near King George VI Sound

An ice cliff approximately 30 ft high was seen between Windy Valley and Cape Berteaux (Fig. 84). The lower part of this cliff was composed of ice containing a high percentage of en glacial material ranging from blocks 5 and more feet in length down to the dust sizes. More or less closely spaced, parallel dirt bands, arching over and sagging under the blocks, are common in this lower ice. The bands appear to be stratification resulting from the deposition of snow and super-glacial moraine and not closely spaced shear planes along which material had been brought from depth. This is perhaps indicated by: (1) The number and closeness of the bands. (2) The absence of bands which cross one another, of offset bands, and of evidence of deformation near the boulders. (3) The volume of en-glacial material. (4) The presence of bands which arch over and sag beneath blocks. A layer of ablation moraine resting on a surface which truncates the bands is found at the top of this ice. There are between 15 and 25 ft of relatively clean ice on top of the ablation moraine. This clean ice appears to be stratified and it also contains several dirt bands. The upper part of the cliff is composed of white snow resting on an ablation surface formed at the top of the clean ice. The stratification in the clean ice is not conformable with either the ablation moraine or the dirt bands in the dirty ice.

During the Red Rock Ridge glacial stage, this area was probably covered with hundreds of feet of ice. Following a period of glacial thinning and retreat, the lower dirty ice was formed when bare bedrock cliffs were common. Later, ablation took place, an unknown thickness of ice was removed, and an ablation moraine was developed. Still later, a period of greater snowfall occurred which resulted in a glacial thickening at this point and probably in a thickening and readvance at other points. Perhaps this readvance correlates with that described by Fuchs (1951, p 405). The duration of the time interval involved in the unconformity between the lower dirty ice and the upper clean ice is not known.

Mushroom Island is about 15 miles southwest of the Terra Firma Islands (Fig. 2). Bedrock crops out on only the northeast side of the island, as elsewhere it is covered with an icecap. Near the east end an ice cliff approximately 45 ft high rests on beach sand and gravel (Fig. 85). Some of the pebbles, cobbles, and boulders of this gravel are excellently rounded. The contact between the top of the beach deposit and the bottom of the ice cliff is approximately 10 ft above sea level and a thickness of about 6 ft of beach gravel is exposed (Fig. 86). Some of these beach gravels have been incorporated within the ice near the bottom of the cliff (Fig. 87). When this material is deposited by the glacier, a roundstone till will be formed whose compaction and lack of stratification will serve to differentiate it from undisturbed beach gravels, just as they served to differentiate the roundstone tills of Patagonia

from the fluvio-glacial deposits from which they were derived (Nichols and Miller, 1951). During the Red Rock Ridge glacial stage, Mushroom Island was probably covered with several hundred feet of ice. Following the deglaciation of the eastern side of the island, a period elapsed during which a considerable thickness of beach gravels was deposited and after which the glacier readvanced and buried the gravels. A climatic change is the conventional explanation for this glacial readvance. As indicated above, however, a tidewater glacier may advance seaward because of a rise of the land with respect to the sea. These beach gravels, now 6 or more feet thick, may have been even thicker before the glacier advanced over them and removed the upper part of them. If they have been elevated since deposition by a rise of the land with respect to the sea, and if the elevation took place before the ice advanced over them, the readvance may have been due to this elevation and not to a climatic fluctuation. The fringing glacier on the south and southeast sides of Neny Island may be resting on beach gravels as a beach is found immediately in front of it.

BARRIER

In most places around Marguerite Bay fringing, valley, cliff, cirque, and piedmont glaciers and shelf ice reach the ocean, forming the well known ice cliff or barrier (Fig. 88). The barrier is usually more or less vertical, crevasses parallel to it are common; it is as much as 200 ft high (Fleming, 1940, p 93) and extends along more than 80 percent of the coastline of Marguerite Bay.

The barrier varies considerably in height from place to place. The thickness, density, and morainal content of the ice are the most important factors controlling the height in free-floating ice masses (Fig. 89D). The height of the barrier of a grounded ice mass is controlled by the thickness of the glacier and the depth of the water (Fig. 90). The farther out the ice pushes into open water, the lower the barrier is, in general. This distance is a function of the rate of forward motion of the glacier and the speed with which the ocean can erode the ice cliff. In detail, the height is controlled by the relief of the topography on which the glacier rests, by differential ablation due to a varying thickness of morainal material, and by the presence of ice calderas (Stephenson and Fleming, 1940, p 160), rifts, lenticular depressions (Knowles, 1945a, p 175), crevasses, and other relief features on the surface of the glacier. David (1914, p 620) thought that the differential height of the barrier of the Ross Shelf Ice was due to tangential and radial undulations on the surface of the shelf ice and to differential erosion of the bottom of the barrier by the Ross Sea currents.

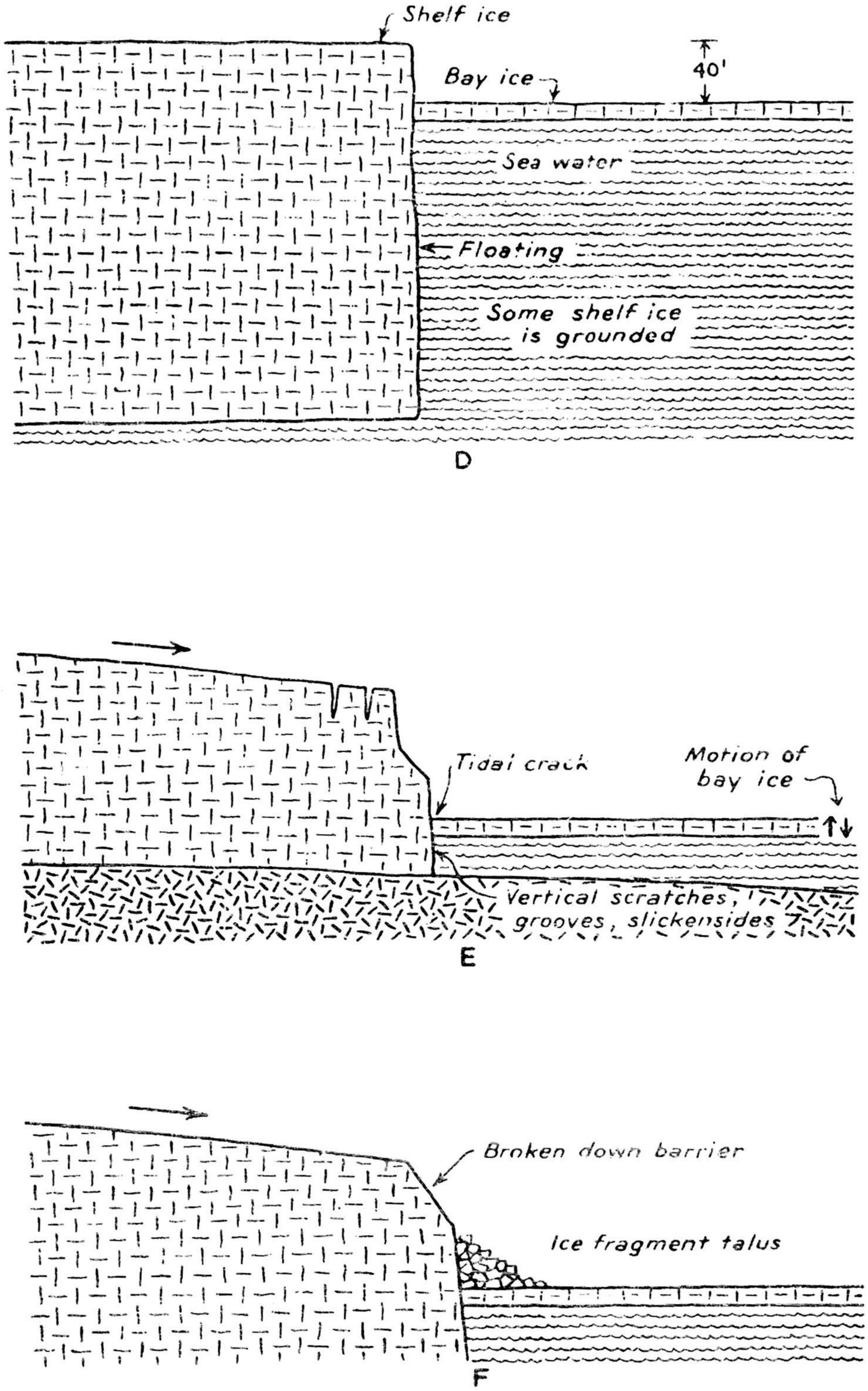


Figure 89 - Diagrammatic Sketches Showing the Characteristics of the Barriers of Shelf Ice and Other Glaciers

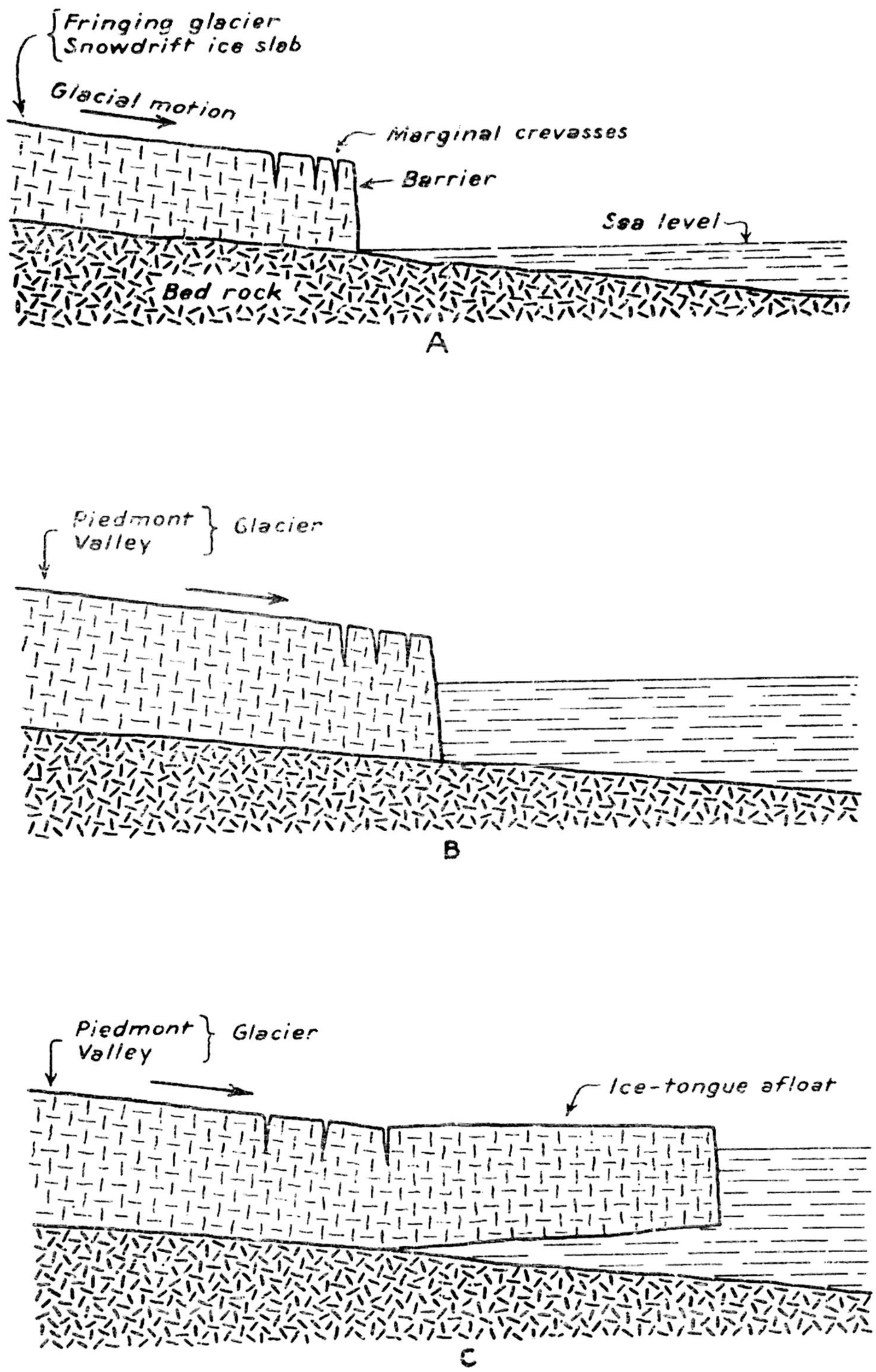


Figure 90 - Diagrammatic Sketches Showing the Positions of the Barriers of Snowdrift Ice Slab and Fringing, Valley, and Piedmont Glaciers

The position of the barrier is determined by the rate of forward movement of the glacier and the speed with which the barrier is pushed back by the attack of the ocean. The ocean will push the barrier back fastest where the waves are strong, the water is warm, and the ice greatly crevassed. The barriers of slow moving fringing glaciers and nearly stagnant snowdrift ice slabs are located not far from the high-tide mark. Examples of this are found on Neny, Stonington, and Mushroom Islands (Fig. 90A). The more rapidly moving valley and piedmont glaciers push farther out into the ocean, but many of them are also grounded (Fig. 90B). The Northeast Glacier near Stonington Island is known by soundings to belong to this group. Glaciers moving still more rapidly may be afloat at their distal end (Fig. 90C). These have been called by Wright and Priestley (1922, pp 156-157) ice-tongues afloat. The Drygalski and Nordenskjöld ice-tongues are well-known examples. The southern side of the terminus of the Neny Glacier may be afloat. The large icebergs which are formed here are suggestive (Fig. 10). The cracks and folding in the nearby sea ice are indicative of a rapidly moving glacier and this, in turn, is a prerequisite for a free-floating terminus (Fig. 10).

The barrier is usually nearly vertical because: (1) The ice is melted and worn back more rapidly at sea level than above. (2) The walls of crevasses, which are usually nearly vertical, control calving. (3) The buoyant action of the water on floating ice sets up stresses which tend to form vertical fractures at the zone where the floating and grounded ice are in contact. The grinding of the bay ice against the barrier and the presence of morainal material near the base of the subaerial part of the barrier would favor verticality.

Figure 91 is a diagrammatic sketch showing that part of the barrier of the Northeast Glacier which is a few hundred feet northeast of the American Base Station on Stonington Island. Among the features seen on this barrier are the following: blue veins, faulted blue veins, open cracks, faulted silt band, and stratified ice in unconformable contact with massive ice. A generalized geologic history of the glacier as read from the barrier follows:

(1) Formation of massive ice (zone of nourishment),

(2) Development of crevasses,

(3) Filling of crevasses to form blue veins,

(4) Faulting of blue veins,

(5) Glacial wastage (zone of wastage)—unknown thickness of ice removed,

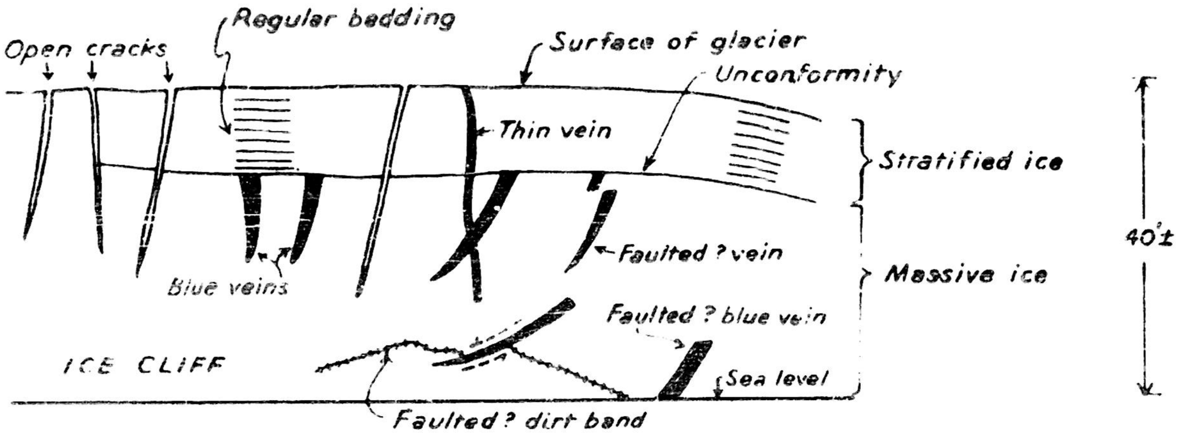


Figure 91 - Diagrammatic Sketch Showing Features Seen on the Barrier of the Noretheast Glacier Near Stonington Island

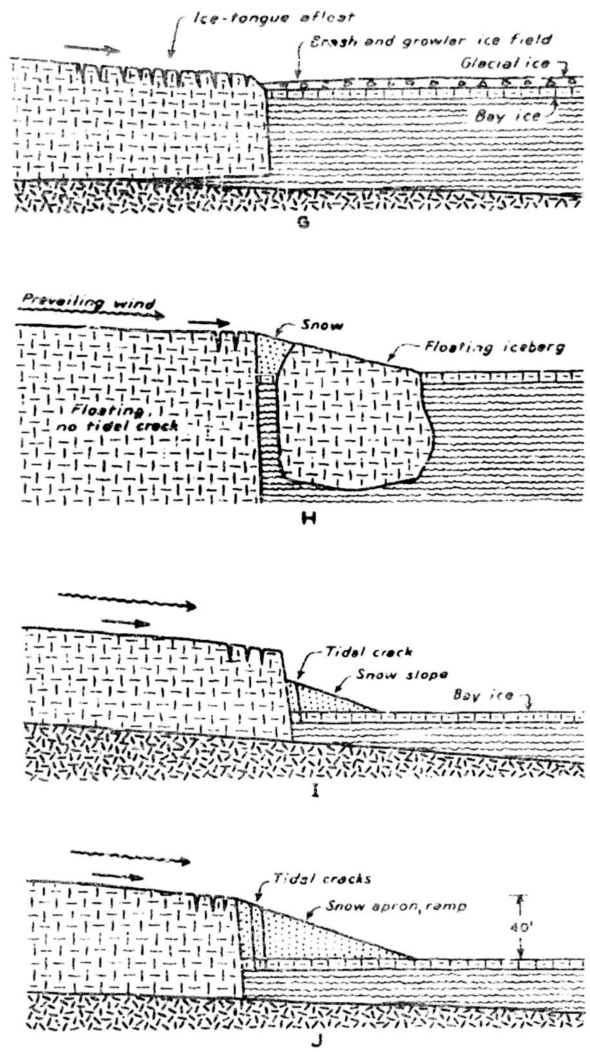


Figure 92 - Diagrammatic Sketches Showing Snow Ramps and a Brash and Growler Ice Field Near a Crevassed Zone

(6) Formation of stratified ice (zone of nourishment),

(7) Thin veins formed in massive and stratified ice,

(8) Open cracks.

The unconformity between the stratified and massive ice is the most important feature in the barrier. The existence of unconformity bergs indicates that it is not an uncommon feature on Antarctic barriers. The fact that unconformities were not seen on the other barriers in the area suggests that this one has only local significance. That the time interval involved in this unconformity was not great is indicated by the following: (1) The unconformity is local rather than regional. (2) No ablation moraine rests on the massive ice. (3) A consideration of the length of the glacier and its rate of movement as indicated by the measurements of Knowles (1945a, p 174) and by the debris field in front of the rapidly moving part of the glacier shows that the ice of which the glacier is composed is probably only a few hundred years old. It is not known how much of the stratified ice has been removed by ablation and other processes. The deposition of the thickness now present would probably have caused no significant readvance of the front of the glacier. This unconformity cannot be correlated with any other features suggesting a glacial readvance in the area late in post-Red Rock Ridge time.

Every stage from the open crevasse, to the crevasse partly filled with blue ice, to the blue vein can be seen on the barriers. A layer of blue ice which was tightly folded was seen on the barrier of the Northeast Glacier. It contained elongated bubbles between 3 and 4 in. long. The presence of the elongated bubbles suggests that it is a deformed blue vein (Wright and Priestley, 1922, p 239-240) and not a deformed stratum of blue ice. The white ice on both sides of the blue ice contained much smaller round bubbles. Sea ice is usually formed next to the barrier during the cold season. A tidal crack commonly separates the sea ice from any barrier which is not floating. On the walls of these tidal cracks, scratches, grooves, and slickensided surfaces are sometimes present (Fig. 89E).

Where elevated beach gravels, talus, moraine, or gently sloping bedrock extend down to the strand line, it is usually easy to get from open water or bay ice up onto the land. Because of the barrier, however, the traveler usually finds it impossible in most places to get up onto land.

The ice cliff is a barrier against travel from either open water or bay ice onto land or from land onto either open water or bay ice. It prevents the geologist from reaching many bedrock outcrops and it makes the traveler more cautious in sledging on disintegrating bay ice

because of the difficulty in getting off the bay ice and onto land. Fortunately for the traveler, however, there are several situations where the barrier along a barrier coastline is either absent or modified in such a way that travel from the bay ice onto land is possible. These will now be considered.

The barrier is not as common on the north side of islands and promontories as on the south side (Fleming, 1940, pp 93, 94). Neny Island is a good example of this. Along the northern side, elevated beaches, talus, and bedrock are present at the strandline, whereas only the barrier of a fringing glacier is found on the south side.

Talus cones and aprons composed of angular fragments of ice deposited on the bay ice and against the barrier are not uncommon. They are usually associated with actively moving glaciers and they may enable the traveler to go from the bay ice up onto land (Fig. 89F).

A snow apron or ramp sometimes forms on the sea ice next to the barrier during the cold season if the right combination of wind direction, supply of snow, thickness of sea ice, and other factors are present (Figs. 92(I, J), 93). One or more tidal cracks are commonly found in the snow aprons which are next to grounded barriers. If the snow slope builds up from the sea ice to the top of the barrier, an easy way of traveling from the sea ice to the glacier is available. Fuchs and Adie sledged from the sea ice to the ice shelf in King George VI Sound by using such a snow slope (Fuchs, 1951, p 414) and Stephenson and Fleming (1940, p 155) reached the surface of the so-called Wordie Shelf Ice from the sea ice by using a similar slope. These slopes are also found on the west side of Stonington Island, on the north side of the Neny Glacier barrier, south of Red Rock Ridge, and elsewhere. Occasionally the space between a barrier and a nearby tilted iceberg will be filled with snow. The traveler can sometimes reach the top of the glacier from the sea ice by using the tilted surface of the berg and the surface of the snow (Fig. 92H).

Medial moraines are found at several places on the glaciers of Marguerite Bay which reach tidewater. If the moraine is thick enough, the barrier is replaced by a slope of morainal material which may extend from the surface of the glacier to the bay ice or to open water (Figs. 94 (M, N)). These morainal slopes are steeper than the normal talus slope. The interstitial ice and snow between the fragments acts as a cement and makes this possible. Travel from the bay ice or from open water onto land is not too difficult at these localities.

The barrier around Marguerite Bay is in places replaced by a snout. The snout enables the traveler to go from bay ice up onto land,

Figure 93 - Ramp Resting on Bay Ice and Against a Barrier, Marguerite Bay

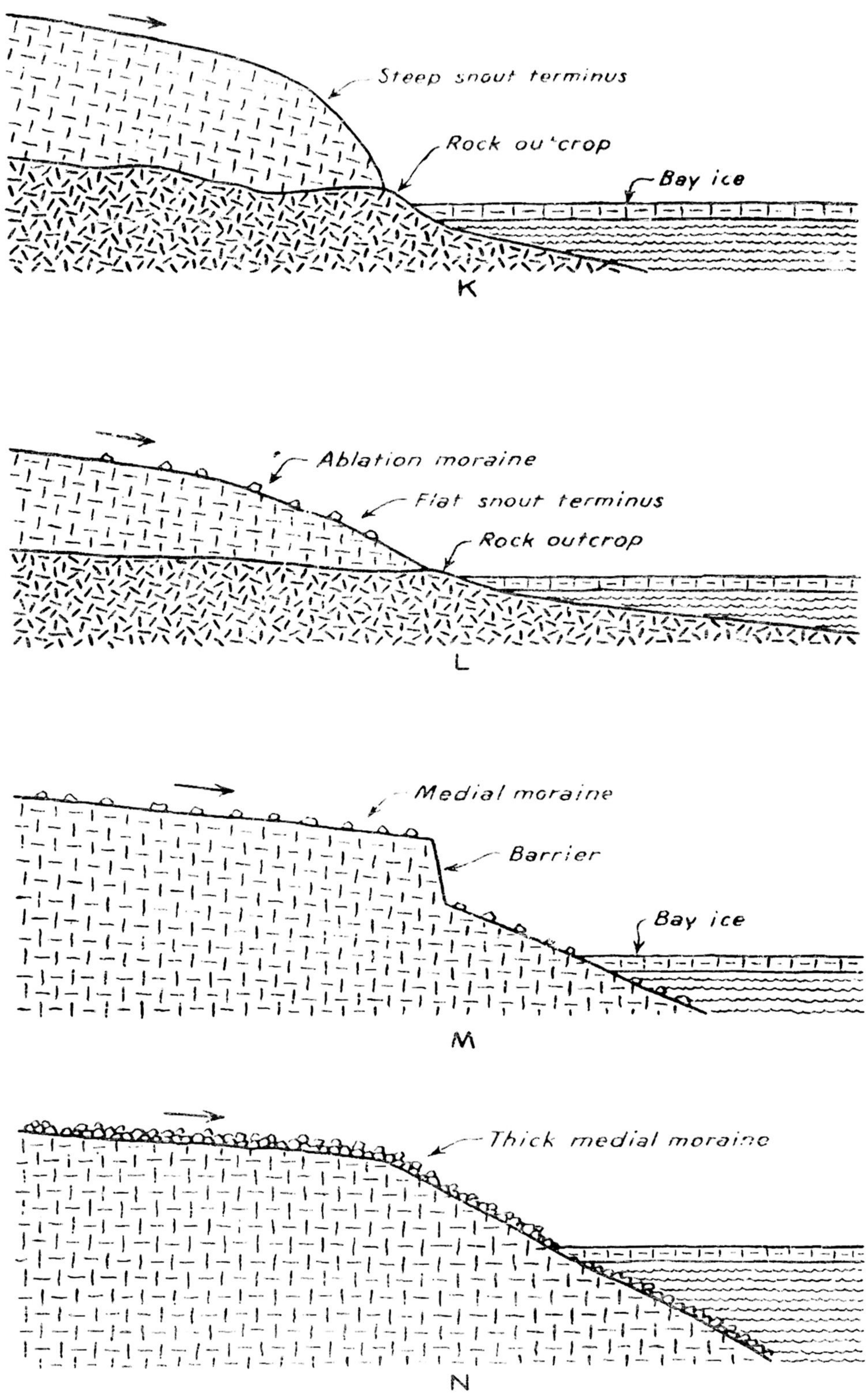


Figure 94 - Diagrammatic Sketches Showing Snout Termini and the Termini of Moraine Covered Glaciers

as the flatter snouts can be climbed easily and the steeper snouts can often be negotiated because of the cracks which are commonly found in the ice (Figs. 94 (K, L).

There is usually a gully between a glacier and a bedrock cliff. Such a gully is found between Roman Four Mountain and the valley glacier immediately north of it, between Black Thumb Mountain and the glacier immediately north of it, and elsewhere. The gully is due to radiation from the bedrock and to the fact that the glacier, because of its movement, does not hug closely to the bedrock cliff. If the bedrock cliff is south of the glacier, the effectiveness of the radiation from the bedrock cliff is increased. If the glacier changes direction abruptly, the gully between the cliff and that part of the glacier downstream from the change in direction is likely to be wider than elsewhere. Wind and running water are of minor importance in the formation and maintenance of this gully. If the glacier and the cliff or the talus or snow slope connected with it reach the bay ice, the presence of the gully will enable the traveler to move directly from the bay ice to land.

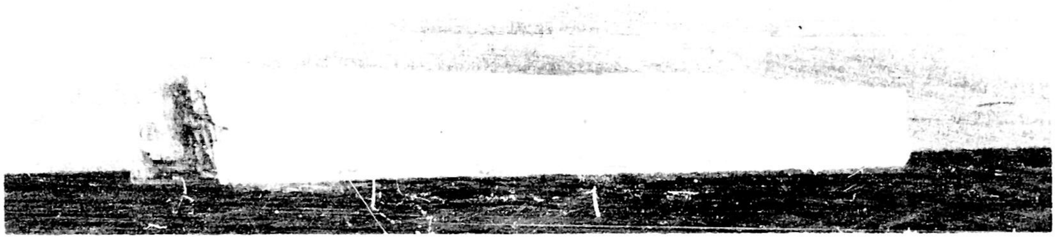
Where bedrock cliffs reach sea level and a bedrock coastline replaces a barrier coastline, the surfaces of the glaciers can sometimes be reached by climbing up the bedrock cliffs.

ICEBERGS

Tabular and irregularly shaped; tilted, weathered, and fluted; and green, blue, white, and black icebergs are common (Figs. 95, 96). Some of the tabular icebergs are hundreds of yards long and they extend scores of feet above sea level. They are commonly stratified because of layers and lenses of blue ice interbedded with white ice. The blue layers may be several or more inches thick, they are more or less parallel to each other and to the tops of bergs, they may be as long as the bergs, and they have sharp contacts with the white ice above and below. No opportunity was available to determine whether the lenses were originally formed as such or whether they were for ed by the erosion of more continuous layers. The sharpness of th lower boundaries of the blue ice layers may argue against their hav ng been formed from melt water. Wade (1945, p 167) has suggested that somewhat similar layers in the Ross Shelf Ice were made when low clouds containing super-cooled moisture came in contact with the surface of the ice.

Bergs with bubble flutings similar to those described by Bretz (1935, pp 240-241) were noted. Icebergs were seen containing contorted dirt bands having dips which vary as much as 90°. This variation in dip pr es that the dirt bands have been deformed. Notches are

Figure 95 - White, Tabular Antarctic Iceberg Probably Broken off From Shelf Ice



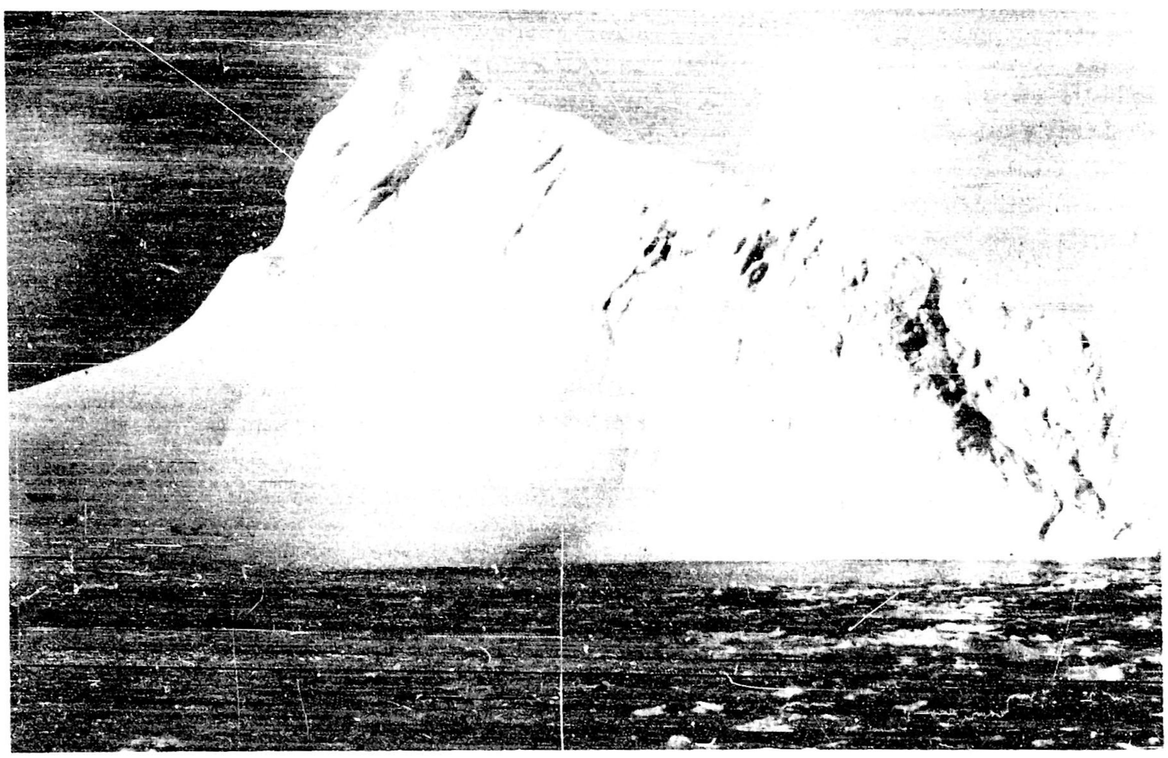


Figure 96 - Tilted Iceberg Showing the Contrast Between Smooth Submarine and Irregular Subaerial Surfaces

commonly formed at the waterline by melting and by wave action. These notches may be enlarged and become caves, and with the passage of time the caves may become tunnels. The caves and tunnels indicate that where they are found, calving is a slow process and that therefore cracks, fissures, and crevasses are not common. It seems likely that such bergs may endure for many years. Caves were not seen in any of the barriers. This is because calving takes place here too rapidly for caves to be formed.

If a glacier pushes far out into the ocean because of rapid movement and a large area of it becomes water-borne, large icebergs may be formed. The large bergs in the Marguerite Bay area are derived from shelf ice and from rapidly moving valley and piedmont glaciers (Fig. 97). The fringing, cliff, cirque, and other small and slow-moving glaciers do not push out far enough to form large icebergs. The abundance of large tabular icebergs close to the barrier of the shelf ice in King George VI Sound indicates that many of them were derived from it. Large, tabular "bread crust" bergs (Gould, 1935, pl 115) break off from the Neny Glacier (Fig. 10) and great numbers of growlers and bergy-bits break off from the Northeast Glacier (Fig. 71).

ICEFOOT

A more or less permanent icefoot, composed of snow, spray ice, as well as shoved and stranded bay and glacial ice, is located a few hundred feet east of the American Base Station on Stonington Island. Resting on elevated beach gravels, this is the only more or less permanent icefoot on the island. It is located at the head of a bight, where not only are the waves weaker than elsewhere, but where the bay ice persists longer, and where it is in the shadow of the Northeast Glacier. Several ice boulders made of glacial ice were seen on the icefoot, one of which, more or less rounded and resting about 3 ft above high tide, was 12 ft long, 5 ft wide, and 3 ft thick. It is not known whether they were deposited by wind waves, by waves formed by capsizing bergs, or by those due to the calving of the nearby Northeast Glacier; or whether they were pushed up by pressure from the bay ice.

BAY ICE

Squeeze-ups. Ridge-like protuberances of ice standing above the bay ice and located along former cracks were seen a short time after the bay ice had grown thick enough to support a man. These may be called linear ice squeeze-ups. They were a few inches high, many feet long, and had vertical sides (Fig. 98A). Following the formation of the

Figure 97 - Tabular Icebergs Probably Derived From Shelf Ice and Irregular Bergs Probably Derived From Fringing and Piedmont Glaciers. Brash and Growler Ice Field Next to Crevassed Zone. Terra Firma Islands in Distance.

bay ice cracks were opened up, new ice was formed in them, and this material was squeezed upward and probably downward because of pressure which developed in the bay ice. The new ice in the cracks could not have been pressed upward if it were hard and rigid, and on the other hand, its vertical sides indicate that it was not too plastic. They remind one of the spine of Mont Pelée which was also pressed upward as a plastic material (Hovey, 1903). Topographically they are similar to the linear squeeze-ups which are common on the surface of pahoehoe basaltic lava flows (Nichols, 1939a).

Another type of ice squeeze-up was seen. These were found in the new ice which had recently formed in cracks. They were wedge-shaped, terminated upward in a sharp edge, and progressively thickened downward. A few inches high, a few feet long, and they extended from the surface of the new ice in the cracks up to the level of the old bay ice (Fig. 98B). There was no opportunity to study these squeeze-ups. They may have been formed by compression, as were the other squeeze-ups. Or they may have been formed in cracks which progressively widened as water or plastic ice was squeezed upwards in them by hydrostatic pressure. The wedge-shaped squeeze-ups in lava are formed in this way (Nichols, 1938, pp. 609-613).

Ponds. The bay ice in Neny Fiord near the south side of the terminus of Neny Glacier has been thrown into a series of open synclinal troughs and anticlinal ridges. They cover hundreds of acres, are roughly parallel to the edge of the glacier, are cut by cracks, and where found, the bay ice was several feet thick (Figs. 99, 100). The distance from ridge to ridge is 50 ft or more and from crest to trough several feet. There was no opportunity to study the cracks. The wide-open, black-looking cracks which are perpendicular to the folds and to the edge of the barrier are due to tension (Fig. 10). Others may be due to shear, still others may be thrust planes, although no topographic evidence of thrusting was ever seen by the writer. The system is not structurally simple, as the bay ice varies in thickness and icebergs are frozen into it. Moreover, in addition to the thrust of the glacier, marine currents and wind also acted on the sea ice. Similar features have been described by Wright and Priestley (1922, pp. 341-354), Gould (1935, pls. 117, 118), and Poulter (1947, Figs. 3, 4). Sea ice can be folded by the thrusting of glaciers into it, by a sudden increase in the temperature of the sea ice, and by other less important factors. The distribution and size of the folds under discussion indicate that they are due to the movement of Neny Glacier.

Ponds more than 900 ft long, 20 to 30 ft wide, and several feet deep occupy the synclinal troughs during the summer months before the break-up of the sea ice. In places they are wider than the ridges

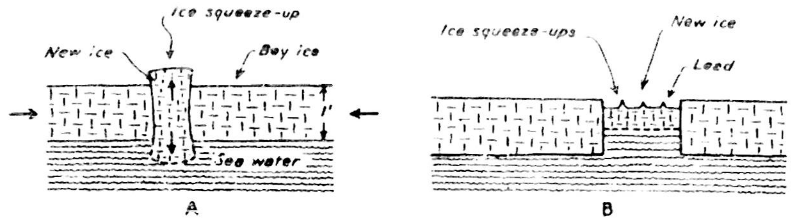


Figure 98 - Two Types of Squeeze-Ups Found on the Bay Ice, Near Stonington Island

Figure 99 - Synclinal Ponds on Folded Bay Ice in Neny Fjord, January 1948

Figure 100 - Synclinal Fresh Water Ponds on Bay Ice Folded by the Thrust of Neny Glacier

which separate them; elsewhere the reverse is true. They are straight, elongate, and simple in outline, although occasionally they bifurcate and ponds in adjoining troughs are connected. Some ponds are connected with the sea water by cracks or thaw holes. Those not connected contain only fresh water, whereas only the surface waters of those which are connected are fresh. Apparently in these cases the warm light fresh water floats on the heavier salt water. Figure 101 (A, B, C) is a series of diagrammatic sketches showing the formation and development of these ponds. Following the formation of the bay ice, folding of it due to the movement of Neny Glacier occurred, and snow accumulated on it. With the arrival of summer and periods with the temperature above 32 °F (Peterson, 1948a, p 7), melting of the snow cover and the sea ice took place. Melt water collected in the troughs, it was heated by solar radiation and by the air temperatures, and honeycombing of the sea ice beneath it took place. This process was continued so that in some of the troughs the sea ice was thawed through (Fig. 101C).

If the free air temperature alone were involved in the destruction of the folded bay ice, the ridges would be more rapidly destroyed than the troughs, as the troughs, before water accumulated in them, would contain colder air on the average and the saturated air would not be blown away from the troughs as readily as from the ridges. After the accumulation of the water in the troughs, the ice in them would not be as easily melted by the free air temperature because the water would act as an insulating blanket. The fact that the troughs have suffered more ablation than the ridges proves, therefore, that solar radiation and not the free air temperature is the agent mainly responsible for the destruction of the bay ice. The water absorbs solar radiation more readily than does the snow and ice, and the ice in the troughs below the ponds is, therefore, more rapidly destroyed than that in the ridges.

Slush. A layer of slushy snow was commonly found between the bay ice and the snow covering it (Peterson, 1948b, p 22). It is difficult to sledge on, as men, huskies, and equipment may break through the upper, dry snow and fall into the slush below. It was sometimes impossible to use weasels on this surface, and the slush made it difficult or impossible for planes to take off from the bay ice. The layer of slush was formed in several ways. Anticlines, synclines, and cracks are found close to the barriers of actively moving glaciers. Slushy snow is found in the synclines. It is commonly formed by flooding when cracks are developed in folded snow-covered bay ice (Fig. 101D). Fortunately this terrain can be avoided by staying a mile or more from the glaciers. Thin bay ice may be so loaded down by a snow cover that the top of it sinks below sea level. If cracks are present in the bay ice, flooding takes place and a layer of slush is formed. The snow on the bay ice melts at the surface during the late spring and summer months

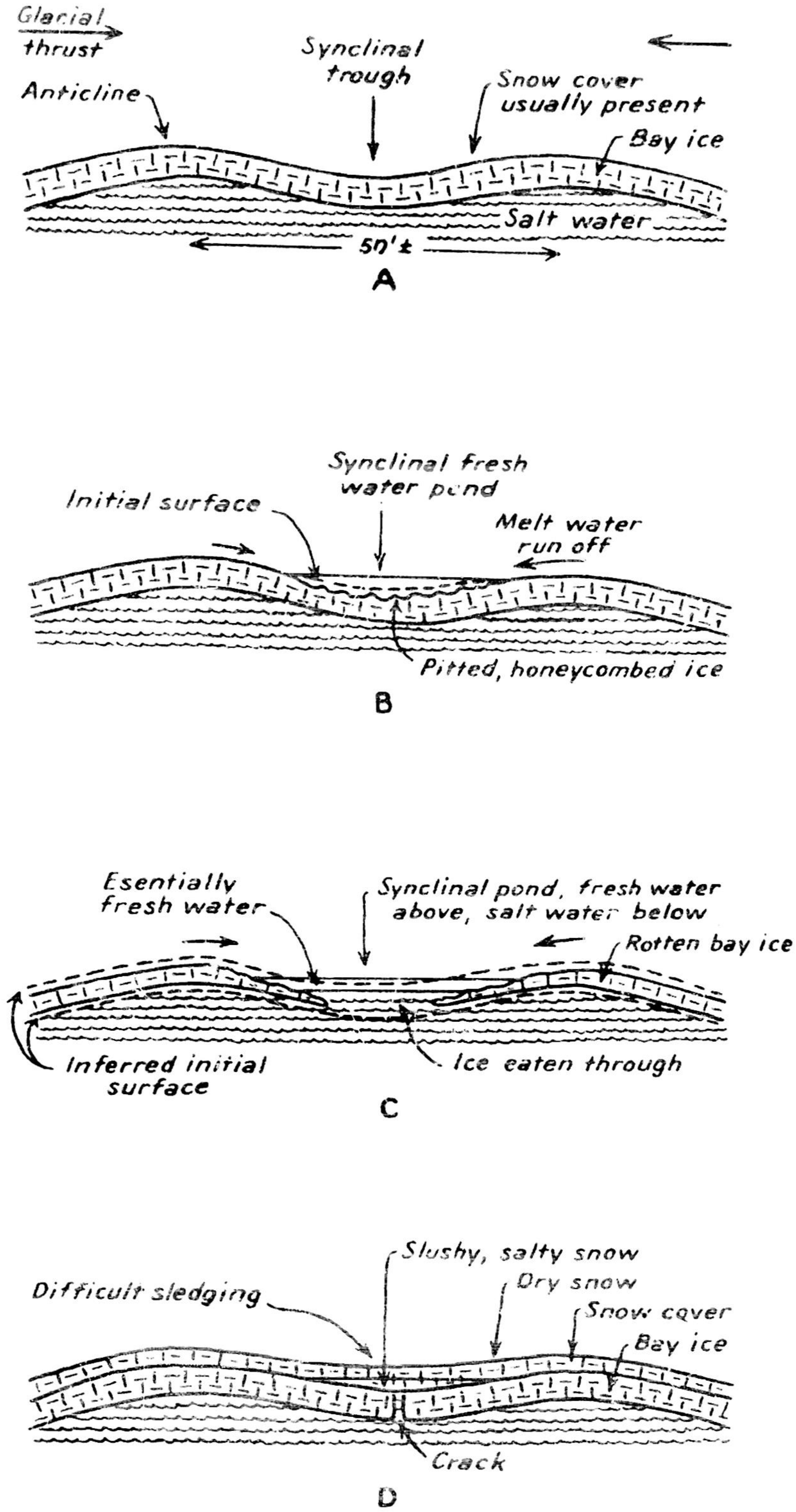


Figure 101 - Diagrammatic Sketches Showing the Formation of Synclinal Ponds and Slushy Snow on Bay Ice

The melt water drains downward until it reaches the impervious bay ice. The accumulation of this melt water on top of the bay ice and at the bottom of the snow cover results in a layer of slush. Slush zones might also be formed after the fall of heavy, wet snow. A layer of slush was found near Stonington Island in May and June, 1947, which perhaps may have been formed as follows: It is well known that the more quickly salt water freezes, the greater the salinity of the ice. Wright and Priestley (1922, p 338) showed that the greatest salt content in the bay ice is found at and near its upper surface. Ice of high salinity and therefore of low melting point will be formed if the ocean freezes during a very cold spell. If, later, snow falls on the bay ice, a layer of slush will be formed when the salty upper part of the bay ice melts because of heat received from the ocean or from the atmosphere.

GLACIOLOGICAL FEATURES RESULTING FROM RADIATION

Cryoconite Holes. Cryoconite pits or fragment wells were seen on flat snow surfaces at the foot of morainal slopes. Some were more than 2 ft deep; they were from 2 to 5 in. wide; the openings of the pits were invariably angular, and at the bottom of each pit there was a small, angular rock fragment. The openings of some of the pits were not much larger than the size of the rock fragments. This indicates that the rock fragments were thin and that they sank rapidly down into the snow. Direct radiation cannot account for their depth; diffused and transmitted radiation can (Sharp, 1949, pp 305-312). The rock fragments were apparently blown from the moraines onto the snow fields.

Dust basins were also found on flat snow surfaces at the foot of morainal slopes. One basin 2 ft deep and 5 ft in diameter was seen. The dust was blown from the moraine onto the snow.

The reconstructed glacier immediately north of Neny Glacier is composed of ice which looks like an ice conglomerate, as roundish masses of blue ice surrounded by a white ice matrix are common. These blue ice masses are without exception round or subround, they vary in size from a few inches up to 3 ft in diameter, and the contacts between them and the white ice are sharp. Hundreds cover the surface of this glacier. When first observed, the writer thought it was actually an ice conglomerate. The blue ice was considered to have come from the lower levels of the highland icecap, the white ice from the upper levels and from the snow which accumulated on the cliffs, and the blue ice was thought to have originally been angular fragments and to have been rounded by attrition and melting. In one case, it was found that the blue ice was several inches thick, that beneath it there was a pit filled with water, that a good-sized rock was at the bottom of the pit,

and that the blue ice was composed of vertical crystals, some of which were four in. long (Fig. 102). In another pit, several small rocks were found at the bottom instead of one large fragment.

These blue areas were apparently formed as follows: Fragments which broke off from the bedrock cliffs fell onto the reconstructed glacier. Round pits were formed as these fragments, heated by insolation, slowly sank into the ice. Later, melt water ran down the slope and filled the pits. With the beginning of cold weather the water in the pits froze, forming the blue, roundish areas. The blue ice is water ice and white ice is snow ice. The melt water probably enlarged the holes because of absorbed solar radiation. The fact that the pit was entirely filled with water below the blue ice proves that it was water tight. The pits were studied on January 26. It seems likely that they were formed earlier in the same year. Those formed the year before and earlier would probably have contained no water—only a solid mass of blue ice. Similar cryoconite holes have been described by Wright and Priestley (1922, pp 283-285).

Sun Cups and Nieves Penitentes. The surface of Neny Glacier was, in places, covered with sun cups on August 18, 1947. There were sharp ice ridges between them, as they coalesced and overlapped. The walls on the south side of the cups were somewhat steeper than those on the north side. Wright and Priestley (1922, p 271) have called this type of surface "thumb-print ice." It seems certain that the cups were formed during the preceding fall and summer as the sun had been above the horizon for only a short time on August 18.

Sun cups, trenches, and ridges and nieves penitentes were seen in snow at several places during December (Matthes, 1934; Nichols, 1939b). Sun cups one foot deep were observed on a steep, north-facing snow slope near Black Thumb Mountain. The slope was too steep for easy traverse but by stepping from sun cup to sun cup travel was not too difficult.

Excellently formed sun trenches were seen on the snow covering the bay ice near Black Thumb Mountain following five cloudless days during which the free air temperature was continuously below 32 °F. The snow cover was essentially flat and the trenches were sunk below its surface 2 or more inches. They were wedge-shaped, as they grew narrower with increasing depth, and their sharp-edged bottoms reached the bay ice. Aligned east-west, they were usually less than one foot long, and dipped southward at an angle approximately equal to the altitude of the sun at noon (Fig. 103A). At a later stage in their evolution, the flat snow surface becomes rough and irregular. The snow near the trenches was more coarsely crystallized than that seen anywhere else

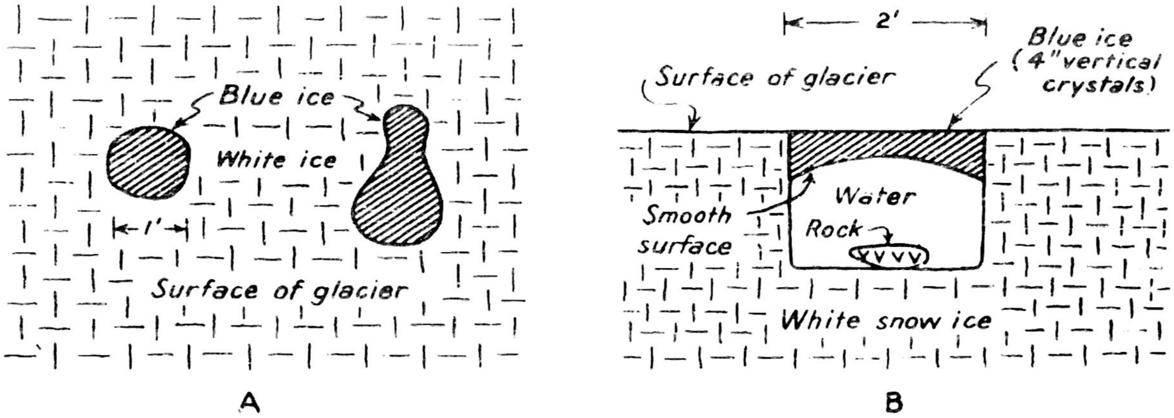


Figure 102 - Diagrammatic Sketches of Cryoconite Hole in a Reconstructed Glacier on North Side of Neny Glacier

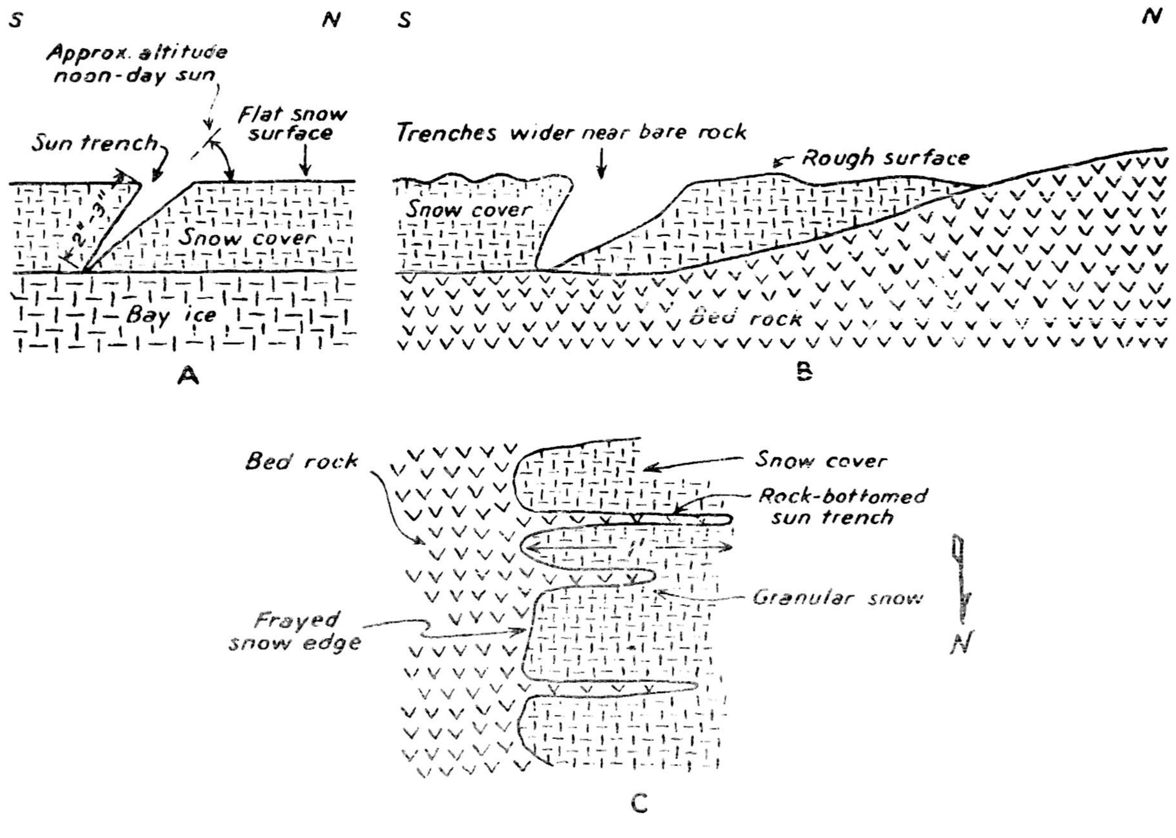


Figure 103 - Diagrammatic Sketches Showing Sun Ridges and Trenches (Nieves Penitentes) at Red Rock Ridge, December 14, 1947

in the Antarctic; some crystals were between 1/2 and 3/4 in. across. The trenches were probably initially located by small irregularities on the snow cover, such as ripple marks or sastrugi. Wright and Priestley (1922, pp 271-273) have described somewhat similar features in East Antarctica which they call plough-share ablation pits.

Sun cups and ridges were very common around the base station late in December. Those close to the buildings were as much as one foot deep. They decreased in size with increased distance from the buildings.

A flattish snow slope adjacent to a steep slope of bare moraine and bedrock was seen at Red Rock Ridge. Nieves penitentes covered the surface of the snow close to the bare rock. Bedrock was found at the bottom of some, they decreased in size and finally disappeared with increased distance from the bare rock, they were almost identical to some seen in Boston, Massachusetts (Nichols, 1939b) (Figs. 103 (B, C), 104). Those close to bare rock tended to be wider although not deeper. These sun cups and nieves penitentes near buildings and rock were formed because of: (1) Direct radiation from the sun. (2) Reflected light from the buildings, rock, and snow surfaces. (3) Radiation of heat from the outer walls of the buildings and from the rock due to absorbed solar radiation. (4) Higher free air temperatures and, therefore, greater ablation because of convection from the rocks and buildings heated by solar radiation. Those near the buildings may also have been due in part to radiation and convection from the outer walls of the buildings due to heat inside the buildings.

These sun cups and nieves penitentes indicate that a considerable percentage of the snow cover on the bay ice and elsewhere is removed by evaporation.

<u>Radiation Gullies</u>. Radiation gullies are common next to outcrops which are close to snow or ice. The largest one seen was next to Neny Glacier (Fig. 105). It was between 15 and 25 ft wide and from 10 to 15 ft deep. The ice cliff was about 10-15 ft high, had a concave profile, and numerous vertical flutes and grooves were found on it. The flutes and grooves are probably due to melt water. A concave profile is in general characteristic of the ice walls next to radiation gullies. It is due, in the case of the larger ones, to the snow which accumulates during the snowy season at the bottom of the gully, which must be removed before the ice beneath it can suffer ablation, and to the fact that the upper part of the ice wall is older than the lower part and hence has retreated farther from the outcrop. The size of a gully is a function of time, of the size, color, and exposure of the outcrop, and of the rate of movement of the ice. The small radiation gullies near small outcrops surrounded by snow fields are completely filled with snow during the

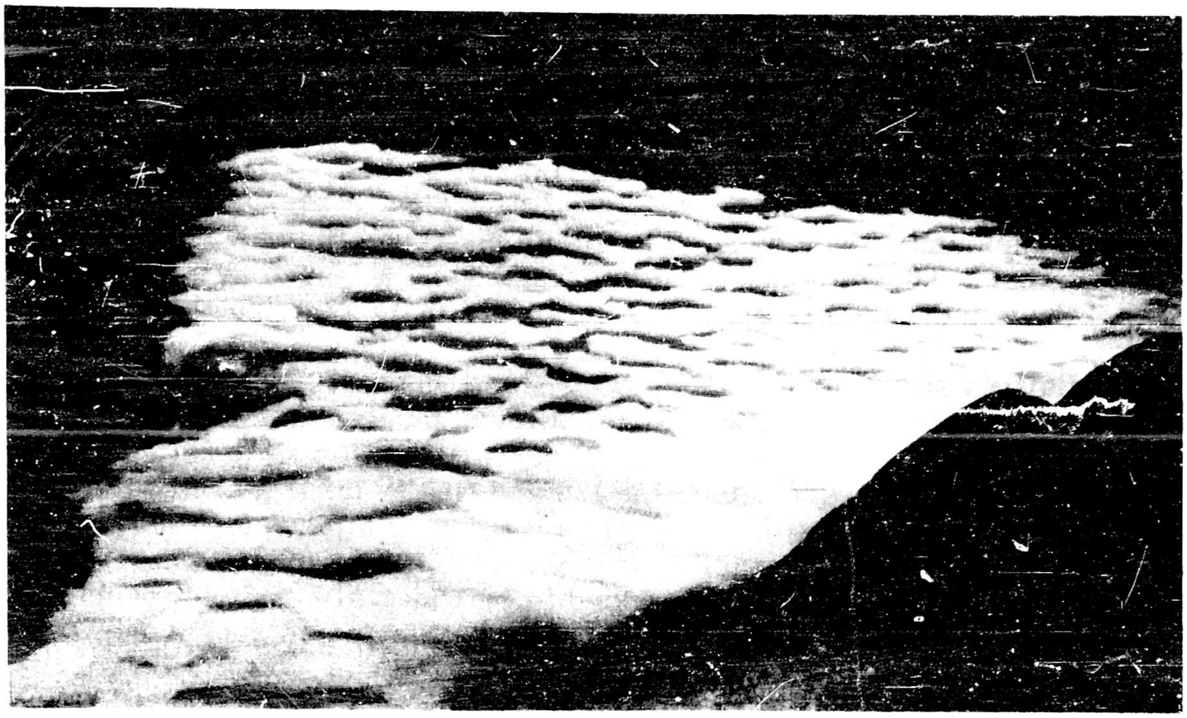


Figure 104 - Photograph of Sun Ridges and Trenches (Nieves Penitentes), Red Rock Ridge

Figure 105 - Radiation Gully Near Terminus of Neny Glacier

winter and are reformed during the spring and summer. The large ones next to glaciers are permanent features and are not completely filled with snow.

Contrast between North- and South-Facing Cliffs. The north sides of some of the promontories and islands in the area are free of snow and ice during the summer months, whereas fringing glaciers are commonly found on the south sides. This is shown on Neny and Millerand Islands and on the south and north sides of Neny Fjord (Fleming, 1940, pp 93, 94). The contrast is due to the difference in solar radiation on the two sides and accounts for the most prominent glaciological feature in the area resulting from solar radiation.

STANDING AND RUNNING FRESH WATER

Radiation moats a foot or more in depth next to north-facing clifflets which are surrounded by snow were seen during March on Stonington Island. Small bodies of standing water are commonly found in these moats (Fig. 106). A small pond more than 40 ft long and a few feet deep was seen in January near Neny Fjord Thumb (unofficial name). This was the largest body of fresh water seen in the Antarctic by the writer. Large lakes on the shelf ice in King George VI Sound and in the recently deglaciated valleys leading down into the Sound, have been described by Ronne (1945, pp 17, 19) and Fuchs (1951, pp 405, 406, 413). The absence of larger lakes in the area studied by the writer is due to the absence of basins rather than to the lack of melt water.

Small streams of water were seen cascading off the Northeast Glacier near Stonington Island, running on the ice along the north side of Neny Glacier, running off the glacier just east of Neny Fiord Thumb (unofficial name), and in the moat between Roman Four Promontory and the valley glacier immediately northeast of it. One of the small streams running off the Northeast Glacier was used by the expedition as a source of water during the summer months. Small waterfalls were seen in January on the bedrock ridge located east of Neny Fjord Thumb (unofficial name).

Water was heard running at this time in the talus near Neny Fjord Thumb (unofficial name) as well as in talus at other places. The thickness of the talus and the closeness of the water to the surface of the talus, as indicated by the sound, suggest that the water was running on ground ice which filled the voids between talus blocks. A low bedrock cliff capped by elevated beach gravels is found at the strandline on the north side of Neny Island. During February, water was emerging at the contact between the beach gravels and the bedrock (Fig. 107).

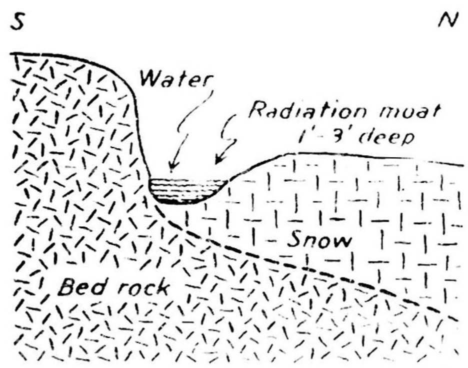


Figure 106 - Water in a Small Radiation Moat, Stonington Island

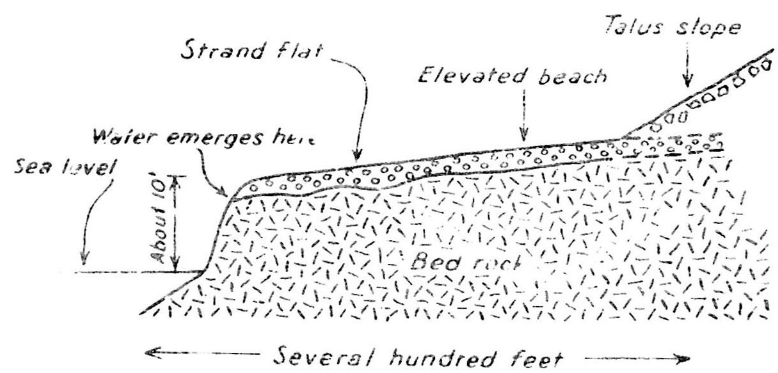


Figure 107 - Water Emerging from the Contact between Elevated Beach Gravels and Bedrock on a Strandflat on North Side of Neny Island

There were undoubtedly many other examples of these features in this area which were not seen. Nevertheless, there is only a very small amount of concentrated running water in this part of the Antarctic during the summer, and none during the winter. It does a small amount of geologic work and is of much less importance as a geologic process than ice, waves and shore currents, and talus-forming processes.

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REFERENCES

Andersson, J. G. (1906) On the geology of Graham Land, Geol. Institution of Univ. Upsala, Bull., vol. 7, 1904-1905, pp 19-71.

Arctowski, H. (1900) The bathymetrical conditions of the Antarctic regions, Appendix No. III in Through the First Antarctic Night by Frederick A. Cook, Doubleday & McClure Co., New York, pp 436-443.

___ (1900) Sur l'ancienne extension des glaciers dans la region des terres découvertes par l'expédition antarctique Belge, Comptes Rendus, Académie des Sciences, Paris, tome 131, pp 479-481.

___ (1908) Géologie, les glaciers, glaciers actuels et vestiges de leur ancienne extension, Expedition Antarctique Belge, Voyage du S. Y. Belgica, 1897-1899, Rapports Scientifiques, pp 59-64.

Ashley, G. H. (1931) Our youthful scenery, Geol. Soc. Am., Bull., vol. 42, pp 537-545.

Bagnold, R. A. (1942) The physics of blown sand and desert dunes, William Morrow & Co., New York City, pp 1-256.

Blackwelder, E. (1928) Mud flow as a geologic agent in semiarid mountains, Geol. Soc. Am., Bull., vol. 39, pp 465-483.

___ (1940) The hardness of ice, Am. Jour. Sci., vol. 238, pp 61-62.

Bongrain, M. (1914) Description des côtes et banquises, Instructions Nautiques, Deuxième Expedition Antarctique Française (1908-1910), Masson et Cie. Editeurs, Paris, pp 1-59.

Bretz, J. H. (1935) Physiographic studies in East Greenland, Am. Geog. Soc., Spec. Publication No. 18, pp 159-245.

Clapp, C. H. (1913) Contraposed shorelines, Jour. Geol., vol. 21, pp 537-540.

Coleman, A. P. (1926) Ice ages, recent and ancient, The MacMillan Co., New York, pp 1-296.

Daly, R. A. (1905) The accordance of summit levels among alpine mountains: the fact and its significance, Jour. Geol., vol. 13, pp 105-125.

(1934) The changing world of the ice age, Yale Univ. Press, New Haven, pp 1-271.

David, T. W. E. (1909) in The Heart of the Antarctic by E. H. Shackleton, J. B. Lippincott Co., Philadelphia, vol. 1, pp 185, 194-195.

(1914) Antarctica and some of its problems, Geog. Jour., vol. 43, pp 605-630.

, and Priestley, R. E. (1909) Geological observations in Antarctica by the British Antarctic Expedition, 1907-1909, in The Heart of the Antarctic by E. H. Shackleton, J. B. Lippincott Co., Philadelphia, vol. 2, pp 276-331.

(1914) Reports on the scientific investigations, glaciology, physiography, stratigraphy, and tectonic geology of South Victoria Land, British Antarctic Expedition, 1907-1909, Heinemann, London, pp 1-319.

Debenham, F. (1921) Recent and local deposits of McMurdo Sound region, British Antarctic ("Terra Nova") Expedition, 1910, Geol., vol. 1, no. 3, pp 63-100.

(1923) The physiography of the Ross Archipelago, British Antarctic ("Terra Nova") Expedition, 1910-1913, Harrison and Sons, Ltd., London, pp 1-40.

(1937) The British Graham Land Expedition, 1934-1937, Geog. Jour., vol. 89, pp 250-253.

(1945) Antarctic regions, Encyclopaedia Britannica, Univ. of Chicago, Chicago, vol. 2, pp 14-20.

Demorest, M. (1942) Glacier regimens and ice movement within glaciers, Am. Jour. Sci., vol. 240, pp 29-66.

Dietz, R. S. (1952) Geomorphic evolution of continental terrace (continental shelf and slope), Am. Assoc. Pet. Geol., Bull., vol. 36, pp 1802-1819.

, and Menard, H. W. (1951) Origin of abrupt change in slope at continental shelf margin, Am. Assoc. Pet. Geol., Bull., vol. 35, pp 1994-2016.

Directorate Colonial Surveys (1948) Falkland Islands Dependencies, South Shetlands and Graham Land, Sheet C, 1:500,000.

Dorsey, Jr. H. G (1945) An Antarctic mountain weather station, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 344-363.

Ferrar, H. T. (1905a) Summary of the geological observations made during the cruise of the S. S. 'Discovery', 1901-1904, in The Voyage of the 'Discovery' by Robert F. Scott, Charles Scribner's Sons, New York, vol. II, pp 437-468.

(1905b) Notes on the physical geography of the Antarctic, Geog. Jour., vol. 25, pp 373-386.

(1907) Report on the field-geology of the region explored during the 'Discovery' Antarctic expedition, 1901-1904, National Antarctic Expedition, 1901-1904, Natural History, Geol., vol. 1, pp 1-100.

Finch, R. H. (1933) Block lava, Jour. Geol., vol. 41, pp 769-770.

Fleming, W. L. S (1940) Relic glacial forms on the western seaboard of Graham Land, Geog. Jour., vol. 96, pp 93-100.

, Stephenson, A., Roberts, B. B., and Bertram, G. C. L. (1938) Notes on the scientific work of the British Graham Land expedition, 1934-1937, Geog. Jour., vol. 91, pp 508-532.

Flint, R. F. (1947) Glacial geology and the Pleistocene Epoch, John Wiley and Sons, Inc., New York, pp 1-589.

Fuchs, V. E. (1951) Exploration in British Antarctica, Geog. Jour., vol. 117, pt. 4, pp 399-421.

Goldring, W. (1922) The Champlain Sea: Evidence of its decreasing salinity southward as shown by the character of the fauna, New York State Mus. Bull., no. 239-240, pp 153-194.

Goldthwait, R. P. (1939) The glacial geology of the Presidential Range, submitted to the Division of Geological Sciences, Harvard Univ., for approval in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

Gould, L. M. (1935) The Ross Shelf Ice, Geol. Soc. Am., Bull., vol. 46, pp 1367-1394.

_____ (1939) The glacial geology of the Pacific Antarctic, 6th Pacific Sci. Cong., Proc , pp 723-740.

_____ (1940) Glaciers of Antarctica. Am. Phil. Soc., Proc., vol. 82, pp 835-877.

Gourdon, E. (1908) Geographié physique, glaciologie, pétrographie, Expedition Antarctique Française (1903-1905), pp 1-214.

Hennig, A. (1911) Le conglomèrat Pleistocéne a Pecten de l'île Cockburn, Wissenschaftliche Ergebnisse, Der Schwedischen Südpolar-Expedition, 1901-1903, Bd. III, Lieferung 10, pp 1-73.

Hobbs, W. H. (1910) The ice masses on and about the Antarctic Continent, Zeitschr. fur Gletscherk., vol. 5, pp 36-73, 87-122.

_____ (1911) Characteristics of existing glaciers, The MacMillan Co., New York, pp 1-301.

Holtedahl, O. (1935) On the geology and physiography of some Antarctic and sub-Antarctic islands, with notes on the character and origin of fjords and strandflats of some northern lands, Scientific Results of the Norwegian Antarctic Expeditions, 1927-1928, vol. 1, pp 1-172.

Hovey, E. O. (1903) New cone of Mont Pelée, Am. Jour. Sci., vol. 16, 4th ser., pp 269-281.

Howard, A. D. (1950) Geomorphology of Antarctica: A summation, Geol. Soc. Am., Bull., vol. 61, pp 1472-1473.

Hydrographic Office (1939) Pacific Ocean, Antarctic regions, Washington, D. C., no. 5411.

Joerg, W. L. G. (1936) The topographical results of Ellsworth's trans-Antarctic flight of 1935, Geog. Rev., vol. 26, pp 454-462.

_____ (1937) The cartographical results of Ellsworth's trans-Antarctic flight of 1935, Geog. Rev., vol. 27, pp 430-444.

Johnson, D. W. (1919) Shore processes and shoreline development, John Wiley and Sons, Inc., New York, pp 1-584.

Joyce, J. R. F. (1950) Notes on ice-foot development, Neny Fjord, Graham Land, Antarctica, Jour. Geol., vol. 58, pp 646-649.

Knowles, P. H. (1945a) Glaciology of southern Palmer Peninsula, Antarctica, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 174-176.

(1945b) Geology of southern Palmer Peninsula, Antarctica, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 132-145.

Mannerfelt, C. M. (1944) Nagra glaciala skulpturer, Ymer-Svenska Sallskapet for Antropologi och Geografi, sextiofjarde argangen, haft I, pp 60-65.

Mason, D. P. (1950) The Falkland Islands Dependencies Survey: Explorations of 1947-1948, Geog. Jour., vol. 115, pp 145-160.

Mather, K. F., Goldthwait, R. P., and Thiesmeyer, L. R. (1942) Pleistocene geology of western Cape Cod, Massachusetts, Geol. Soc. Am., Bull., vol. 53, pp 1127-1174.

Matthes, F. E. (1900) Glacial sculpture of the Bighorn Mountains, Wyoming, U. S. Geol. Survey, 21st Ann. Rept. (for the year) 1899-1900, pt. 2, p 190.

(1934) Ablation of snow-fields at high altitudes by radiant solar heat, Am. Geophysical Union, Tr., pt. II, pp 380-385.

Mawson, D. (1914) The home of the blizzard, J. B. Lippincott Co., Philadelphia, vol. I, pp 1-349.

(1935) The unveiling of Antarctica, Australian and New Zealand Association for the Advancement of Science, Rept. of the 22nd Meeting, Melbourne, Australia, vol. 22, pp 1-37.

McConnell, R. G. and Brock, R. W. (1904) The great landslide at Frank, Alta., 1903, Dept. Interior, Canada, Ann. Rept., 1903, pt. 8, pp 1-17.

Nichols, R. L. (1937) New mechanism for the formation of kettleholes and eskers, Geol. Soc. Am., Proc., 1936, pp 403-404.

(1938) Grooved lava, Jour. Geol., vol. 46, pp 601-614.

(1939a) Squeeze-ups, Jour. Geol., vol. 47, pp 421-425.

(1939b) Nieves penitentes near Boston, Massachusetts, Science, vol. 89, pp 557-558

(1947a) Elevated beaches of Marguerite Bay, Antarctica, Geol. Soc. Am., Bull., vol. 58, p 1213.

(1947b) Geology of Stonington Island area, Marguerite Bay, Antarctica, Geol. Soc. Am., Bull., vol. 58, p 1213.

(1948a) Preliminary report on the geology of the Marguerite Bay area, Antarctica, Technical Rept. no. 6 by the Ronne Antarctic Research Expedition under contract no. N6onr280 with the Geophysics Branch, Office of Naval Research, Dept. of the Navy, Washington, D. C., pp 1-5.

(1948b) Flying bars, Am. Jour. Sci., vol. 246, pp 96-100.

(1953) Marine and lacustrine ice-pushed ridges, Jour. Glaciology, vol. 2, pp 172-175.

, and Miller, M. M. (1951) Glacial geology of Ameghino Valley, Lago Argentino, Patagonia, Geog. Review, vol. 41, pp 274-294.

Nordenskjöld, O. (1904) Résultats scientifiques de l'expèdition antarctique suèdoise (1901-1903), La Gèographie, Soc. de Gèogr., Bull., vol. 10, pp 351-562.

(1911) Die Schwedische Südpolar-Expedition und ihre geographische Tätigkeit, Wissenschaftliche Ergebnisse Der Schwedischen Südpolar-Expedition, 1901-1903, Lithographisches Institut des Generalstabs, Stockholm, pp 1-232.

(1913) Antarktis, Handbuch der Regionalen Geologie, Heidelberg, pp 1-29.

, and Andersson, G. (1905) Antarctica or two years amongst the ice of the South Pole, The MacMillan Co., New York, pp 1-608.

Peltier, L. C. (1950) The geographic cycle in periglacial regions as it is related to climatic geomorphology, Annals of the Association of Am. Geographers, vol. 40, pp 214-236.

Peterson, H. C. (1948a) Antarctic weather statistics compiled by Ronne Antarctic Research Expedition, Office of Naval Research, Dept. of the Navy, Washington, D. C., pp 1-42.

(1948b) Guide for Stonington Island aviation meteorology -- compiled by Ronne Antarctic Research Expedition, Office of Naval Research, Dept. of the Navy, Washington, D. C., pp 1-25.

Philippi, E. (1912) Geologische Beschreibung des Gaussbergs Deutsche Südpolar-Expedition, 1901-1903, Georg Reimer, Berlin, II Bd., Geographie and Geologie, pp 1 -[illegible].

Poulter, T. C. (1947) Seismic measurements on the Ross Shelf Ice, Part I, Am. Geophysical Union, Tr., vol. 28, no. 2, pp 162-170.

Priestley, R. E. (1909) Scientific results of the western journey geological and geographical, in The Heart of the Antarctic by E. H. Shackleton, J. B. Lippincott Co., Philadelphia, vol. 2, pp 332-353.

(1923) Physiography (Robertson Bay and Terra Nova Bay regions), British Antarctic ("Terra Nova") Expedition, 1910-1913, Harrison and Sons, Ltd., London, pp 1-87.

, and David, T. W. E. (1912) Geological notes of the British Antarctic Expedition, 1907-1909, Compte Rendu, Cong. Gèol. Internat., XI:E Session, Stockholm, 1910, pp 767-811.

Racovitza, E. (1900) General results of the Belgian Antarctic Expedition, Appendix no. 1 in Through the First Antarctic Night by Frederick A. Cook, Doubleday & McClure Co., New York, pp 409-424.

Ronne, F. (1945) The main southern sledge journey from East Base, Palmer Land, Antarctica, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 13-22.

(1948) Ronne Antarctic Research Expedition, 1946-1948, Geog. Rev., vol. 38, no. 3, pp 355-391.

Roos, S. E. (1937) Some geographical results of the second Byrd Antarctic Expedition, 1933-1935, I. The submarine topography of the Ross Sea and adjacent waters, Geog. Rev., vol. 27, pp 574-583

Rymill, J. R. (1938) British Graham Land Expedition, 1934-1937, Geog. Jour., vol. 91, pp 424-438.

Sayles, R. W. (1914) The Squantum Tillite, Mus. Comp. Zool., Bull. (Harvard College), vol. 56, pp 141-175.

Scott, R. F. (1905a) The Voyage of the 'Discovery', Charles Scribner's Sons, New York, vol. II, pp 1-508.

______ (1905b) Results of the National Antarctic Expedition, I. Geographical, Geog. Jour., vol. 25, pp 353-373.

Seligman, G. (1947) Extrusion flow in glaciers, Jour. Glaciology, vol. 1, pp 12-21.

Sharp, R. P. (1948) The constitution of valley glaciers, Jour. Glaciology, vol. 1, pp 182-189.

______ (1949) Studies of superglacial debris on valley glaciers, Am. Jour. Sci., vol. 247, pp 289-315.

Shepard, F. P. (1948) Submarine geology, Harper & Brothers Publishers, New York, pp 1-348.

Smith, H. T. U. (1949) Physical effects of Pleistocene climatic changes in nonglaciated areas; eolian phenomena, frost action, and stream terracing, Geol. Soc. Am., Bull., vol. 60, pp 1485-1515.

Stephenson, A. (1940a) Graham Land and the problem of Stefansson Strait, Geog. Jour., vol. 96, pp 167-180.

______ (1940b) British Graham Land Expedition -- sledge journeys and flights from the Southern Base -- scale 1:1,000,000, Geog. Jour., vol. 96, no. 3, p 232.

______, and Fleming, W. L. S. (1940) King George the Sixth Sound, Geog. Jour., vol. 96, no. 3, pp 153-166.

Stose, G. W. (1950) Geologic map of South America, 1:5,000,000, Geol. Soc. Am., New York.

Taylor, G. (1914) Physiography and glacial geology of East Antarctica, Geog. Jour., vol. 44, pp 365-382, 452-467, 553-571.

______ (1922) The physiography of the McMurdo Sound and Granite Harbour region, British Antarctic ("Terra Nova") Expedition, 1910-1913, Harrison and Sons, Ltd., London, pp 1-246.

______ (1930) Antarctic adventure and research, D. Appleton and Co., New York, pp 1-244.

Teichert, C. (1939) Corrosion by wind-blown snow in Polar regions, Am. Jour. Sci., vol. 237, pp 146-148.

U. S. Army Air Forces Aeronautical Chart Service (1949) AAF Aeronautical Chart South Shetland Islands, 1737, 1:1,000,000.

(1950) AAF Aeronautical Chart Adelaide Island, 1762, 1:1,000,000.

U. S Navy Dept., Hydrographic Office (1939) Pacific Ocean -- Antarctic regions, H. O., no. 5411.

(1943) Sailing directions for Antarctica, H. O., no. 138, pp 1-312.

(1943) Antarctica, H. O., no. 2562.

Wade, F. A. (1937) Some geographical results of the Second Byrd Antarctic Expedition, 1933-1935, II. Northeastern borderlands of the Ross Sea: Glaciological studies in King Edward VII Land and northwestern Marie Byrd Land, Geog. Rev., vol. 27, pp 584-597.

(1945a) The geology of the Rockefeller Mountains, King Edward VII Land, Antarctica, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 67-77.

(1945b) The physical aspects of the Ross Shelf Ice, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 160-173.

Warner, L. A. (1945) Structure and petrography of the Southern Edsel Ford Ranges, Antarctica, Reports on Scientific Results of the United States Antarctic Service Expedition, 1939-1941, Am. Philosophical Soc., Philadelphia, pp 78-122.

Washburn, A. L. (1947) Reconnaissance geology of portions of Victoria Island and adjacent regions Arctic Canada, Geol. Soc. Am., Mem. 22, pp 1-142.

Webb, E. N. (1913) Observations in the South Magnetic Pole area, Nature, vol. 91, pp 648-651.

Wentworth, C. K. (1936) An analysis of the shapes of glacial cobbles, Jour. Sed. Petro., vol. 6 pp 85-96.

Wright, C S (1923) Physiography of the Beardmore Glacier region, British Antarctic ("Terra Nova") Expedition, 1910-1913 Harrison and Sons, Ltd., London, pp 1-25

, and Priestley, R E (1922) Glaciology, British Antarctic ("Terra Nova") Expedition, 1910-1913 Harrison and Sons, Ltd , London, pp 1-581.

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